STUDY OF THE EFFECT OF GA_3, N, P, K AND Ca APPLICATION ON THE PERFORMANCE OF MUSTARD

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Dedicated

To

My Parents

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Certificate

This is to certify that the thesis entitled **"Study of the Effect of GA_3, N, P, K and Ca Application on the Performance of Mustard"** submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Botany, is a faithful record of the bonafide research work carried out at the Aligarh Muslim University, Aligarh by **Ms. Shaheena Afroz** under my guidance and supervision and that no part of it has been submitted for any other degree or diploma.

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Shaheena Afroz

CONTENTS

Introduction

Chapter 1

INTRODUCTION

Fat is one of the essential components of our diet. The main source of fat is cooking oil which is obtained from various sources, including butter, cheese, coconut oil, meat and palm oil (saturated fats); canola, olive and peanut oils (monosaturated fats); and safflower, sesame, sunflower and corn (polyunsaturated fats). Fat provides essential fatty acids (linoleic and linolenic acid) necessary for the structural components of cell membranes and prostaglandins. The latter play a role in a number of body functions, including hormone synthesis, immune function, regulation of the response to pain and inflammation, blood vessel constriction and other heart and lung functions. Fat provides a vehicle for transport of many substances, including vitamin A, D, E and K, required in metabolism. In addition, it furnishes more than double the calories compared with carbohydrate and protein (Nelson and Cox, 2000; Prakash *et al.*, 2000, 2003a,b).

In comparison with animal fat, edible vegetable oil has higher proportion of polyunsaturated fatty acids and thus it is helpful in the prevention of cardiac heart disease as saturated fatty acids are known to increase blood cholesterol levels and is a good source of natural antioxidants. Moreover, the phospholipids of vegetable oils are important for the stability of cell membranes and their deficiency may affect satisfactory psychomotor development (Kaur and Islam, 2003; Prakash *et al.*, 2003). The seed meal, remaining after extraction of oil, is a valuable animal feed being high in protein and may also be used as manure and as nematicide (Bharti *et al.*, 2003).

Edible vegetable oil is obtained from many crops in various countries of the world, the major crops including copra, cottonseed, groundnut, niger, olive, palm, rapeseed-mustard, safflower, sesame, soyabean and sunflower (Weiss, 1983). In India, edible oils and fats are derived mainly from groundnut, rapeseed-mustard, safflower, sesame, soyabean and sunflower. Other important sources are coconut, cottonseed, palm and rice bran. The non-edible oils and fats, basically for industrial use, are obtained from linseed, castor and seeds of some trees (Saxena, 2000). In the agricultural economy of this country, oilseeds stand next to food grains in acreage, production and value. According to an estimate, the area under oilseed cultivation was around 26 million hectares (Saxena, 2000) and production, about 24.8 million tonnes during 2004-2005 (Anonymous, 2006). In the global context, India has the dubious distinction of having around 19% of world's total oilseed area but produces only 10% of the world's oilseeds except castor (Shukla *et al.*, 2000; Hegde, 2002).

Oilseed program picked up the needed momentum in 1967, when the All India Coordinated Research Project on Oilseeds was established by the Indian Council of Agricultural Research to initiate and coordinate research and development of major oilseed crops. The Project Directorate on Oilseed Research was established in 1976 at Hyderabad (A.P.). With the setting up of the Technology Mission on Oilseeds in May, 1986, the oilseed scenario has undergone a dramatic change, oilseed production being more than doubled and self sufficiency achieved in the span of a decade from 1985-86. However, the growth rates in area, production and productivity of oilseeds have been drastically reduced during the past few years (Hegde, 2002). Thus, a gap between production and consumption still persists.

Consumption of edible oil has continuously increased during the last one decade, owing to a perceptible improvement in our standard of living facilitating increase in per capita consumption (Hegde, 2002). However, it is still low (8.2 kg/capita/year) in comparison with the minimal nutritional requirements, i.e. 12 kg/capita/year (Shukla *et al.*, 2005). With stagnant or declining production on the one hand and increasing consumption on the other, the supply: demand gap has widened significantly over the past years and had to be met through imports of more than one million tonnes every year (Batra, 2000; Hegde, 2002).

Rapeseed-mustard is an important edible oilseed crop which is grown annually on about 25.2 million hectares globally, 20.9% of which is in India with 12.8% production (Kolte, 2005), the crop occupying an area of about 6 million hectares with about 6 million tonnes production annually. To improve its production, a separate Project Coordinator was provided exclusively for research and development of rapeseed-mustard at Hyderabad (A.P.) when the All India Coordinated Research Project on Oilseeds (see above) was established, followed by collaboration from the International Development Research Centre of Canada and the Swedish Development Agency. In 1994, the Rapeseed and Mustard Research Unit was elevated to work independently and the All India Coordinated Research Project on Rapeseed and Mustard along with a Coordinating Unit was established at Bharatpur, Rajasthan. The overall aim of these measures was to strengthen research and popularization of improved cultivars and to enhance crop productivity and production through timely transfer of available advanced production and protection technologies. As a result, there has been a

continuous uptrend in the growth rate of rapeseed and mustard leading to what is commonly called "Yellow Revolution" (Bhowmik, 2003). Inspite of such efforts, the average productivity (1000 kg/ha) is far below the world average of 1500 kg/ha (Kolte, 2005). Among the rapeseed-mustard group, mustard (*Brassica juncea* L. Czern. & Coss.) is the major crop, occupying around 90% of area under this group (Prakash *et al.*, 2004). Mustard oil is the most favoured edible oil especially in northern India (Prakash *et al.*, 2003b). In addition to the use of mustard oil as such, some mustard oil is used in the manufacture of *vanaspati*, i.e. hydrogenated oil (Anonymous, 1988). It is a good source of the required ratio of omega-3 fatty acid (linolenic)/omega-6 fatty acid (linoleic acid), is a natural antioxidant and is known to reduce the risk of diseases and thus enhances the quality of life (Prakash *et al.*, 2001). Mustard oil contains 30% protein, calcium, phytins, phenolics and natural antioxidants (Kaur and Islam, 2003). The seed meal, remaining after extraction of oil, is also a valuable animal feed, high in protein, which can be used in place of imported soyabean or other animal feed products (Bharti *et al.*, 2003). Mustard seed meal is a rich source of edible protein (about 45-55%) with balanced amino acid composition, which is comparable with the milk protein casein (Sen and Bhattacharyya, 2000). The presence of sulphur-containing amino acids is an added advantage for mustard meals. Thus, mustard seed meal could be considered a good source of protein for direct human consumptions (Ghosh, 2005).

More than 30 million people are engaged in the production of mustard and another 30 million in their post harvest operations, a large number of people being thus dependent on mustard for their livelihood.

Mustard, therefore, is much more than just a cooking medium for us. It is a major socio-economic factor in the well being of our society (Mathur and Bharti, 2003).

Growth and maturity of a crop are controlled by a number of environmental factors that determine its adaptation in a range of cropping systems. Short duration varieties offer greater flexibility for incorporation in different traditional and non-traditional cropping systems. Significant progress has been made in development of short duration mustard varieties which mature in about 100 days compared with traditional varieties like Varuna which matures in 130-135 days. However, a yield loss has been observed in short duration mustard varieties (Singh, 2003).

Efforts are currently under way to improve the yield of low erucic acid lines at various centres, including the Punjab Agriculture University, Ludhiana, Punjab (Banga *et al.*, 1998); the Indian Agricultural Research Institute, New Delhi; the Tata Energy Research Institute, New Delhi (Agnihotri and Kaushik, 1999), and the National Research Centre for Rapeseed-mustard, Bharatpur, Rajasthan (Singh, 2003), as high content of erucic acid is considered harmful for human health.

The productivity level of rapeseed and mustard in India is low compared with the world average and stands nowhere when countries like France, Germany, Sweden and China are considered (Bhowmik, 2003). To improve the situation, emphasis has to be given to vertical growth of the crop as nothing can be done to bring more land under oilcrops due to the high priority accorded to food grains. Further, the wide gap in yields between improved practices and farmers' traditional ones needs to be narrowed to ensure that productivity is enhanced further (Kumar, 1999).

There are several factors responsible for low production of oilseeds in India. Important ones include:

(i) small agricultural holdings - more than 75% of the farmers have small or marginal holdings measuring less than two hectares,

(ii) lack of irrigation facilities - less than 25% of the area under oilseeds is under irrigation compared with approximately 90 and 50% under wheat and rice respectively,

(iii) lack of modern scientific knowledge - most farmers are ignorant of the techniques of cultivation of high yielding varieties, post harvest technology and proper processing facilities,

(iv) susceptibility to pests and diseases – these reduce the yields further as, compared with cereals, oilseeds are more prone to these,

(v) infertility problem - number of flowers produced is more than that of pods, only 68% flowers develop into pods,

(vi) frigidity - low temperature influences the flower bud development and thereby lowers the seed yield,

(vii) lack of balance among indigenous growth factors - internal hormonal imbalance during the sink development,

(viii) partitioning - improper source-sink relationship, and

(ix) ignorance of fertilizer requirement - lack of knowledge of the precise dose of fertilizers recommended by the Agricultural Department for a particular cultivar and region (Siddiqui, 1999, 2005; Batra, 2000; Khan, 2000; Khan *et al.*, 2002; Anonymous, 2004; Afroz *et al.*, 2005).

Like other crop plants, high yielding varieties of oilseeds, including mustard, require large amount of nutrient inputs; but the cash-strapped farmers can not afford the high price of fertilizers. Moreover, when the full dose of fertilizers is applied basally, as single application, much of it is rendered unavailable to plants due to many factors. For example, up to 50% of the applied nitrogen may be lost through leaching, decomposition, volatilization, etc. (Anonymous, 1971; Dejoux *et al.*, 2003) and up to 70% of the phosphorus, by fixation (Russell, 1950; Gikaara *et al.*, 2004). As mentioned earlier, a majority of farmers (75%) has marginal holdings of less than two hectares. Therefore, with such a limitation on increasing the acreage for cultivation, it is highly desirable to innovate ways which can augment the yield and ensure economic cultivation of the crop. To achieve this, one of the ways could be to make plants utilize maximum possible available resources leading to maximum reaping of solar energy and subsequently increasing the number of active sinks and translocating the stored dry matter to the developing sinks. In this context, growth regulators are thought to be a trendsetter. They are known to be actively involved in various physiological activities such as, growth, flowering, fruiting and ion-transport (Wareing and Phillips, 1981; Khan *et al.*, 2002; Khan and Samiullah, 2003).

It may, however, be emphasized that, in addition to their favourable effect on growth and development of plants, phytohormones may sometimes cause undesirable characteristics leading to poor yield. For example, application of gibberellic acid (GA_3) improves growth and differentiation, including plant height that ultimately leads to substantial loss in yield due to

lodging. Such losses due to lodging could be reduced if plants are strengthened by some means. In this regard, calcium (Ca) may be helpful in providing mechanical strength to the plants by entering the middle lamellae in the form of calcium pectate. Ca is involved in cell elongation and cell division, influences the pH of cells and also acts as a regulatory ion in the translocation of carbohydrates (Hirschi, 2004). Transport of Ca through the endoplasmic reticulum membranes is enhanced by GA_3, leading to typical stimulation of alpha-amylase activity in aleurone cells (Bush *et al.*, 1993). Moreover, Ca functions as a second messenger in the signal transduction between environmental factors and plant responses in terms of growth and development (Marschner, 2002). Keeping this importance of Ca in view, it is desirable to include this element with the highly demanded elements nitrogen (N), phosphorus (P) and potassium (K) in the mineral nutrient study of mustard crop.

It was, therefore, decided to study the effect of the phytohormone GA_3 and nutrient application management on various growth characteristics, physiological and biochemical markers and yield and quality parameters of mustard by performing four pot experiments as under.

The first experiment was planned to select the most promising variety of mustard on the basis of a varietal trial on eighteen varieties grown with a uniform basal dose of N, P and K.

The second experiment was aimed to determine the best concentration of GA_3 for pre-sowing seed treatment and/or spray, using Rohini as the test crop (selected on the basis of the data of Experiment 1) grown with the same basal dose of N, P and K.

The third experiment was planned to establish the N and P requirement of Rohini grown with the best combination of soaking and spray application of GA_3 emanating from the data of Experiment 2.

The fourth experiment was planned to determine the best dose of Ca spray applied on Rohini grown with the best combination of soaking plus spray application of GA_3 (selected in Experiment 2) and of basal N and P dose (established in Experiment 3).

Each experiment was planned, and its results analyzed, statistically according to Gomez and Gomez (1984). The significant data are discussed in the light of the results of others engaged in research on rapeseed-mustard.

Review of Literature

CONTENTS

Chapter 2

REVIEW OF LITERATURE

2.1 Introduction

Cultivation of crop plants is as old as our civilization. However, due to ever increasing wide gap between demand and production, a need for an improvement in their productivity has always been felt. In due course of time, the endeavours of plant scientists made it clear that the yield of a crop could be improved to a great extent through proper nutrition, plant protection measures, high yielding varieties, improved agronomic practices, internal hormonal balance and source-sink relationship. In the following pages, an effort has been made to review the available literature on the general aspects of mustard, on phytohormones and mineral nutrition and on crop response to the exogenous application of GA_3, N, P, K and Ca.

2.2 Rapeseed – mustard

Several oilseeds belonging to the family Brassicaceae are grown in India under the name rapeseed-mustard. They can be divided into four groups (Singh, 1958; Anonymous, 1988; Reddi and Reddy, 2003).

(A) *Sarson* (Indian colza)

(i) Yellow *sarson* – *Brassica campestris* L. var. *sarson* Prain

(ii) Brown *sarson* – *Brassica campestris* L. var. *dichotoma* Watt

Sarson is considered to correspond to European colzas – *Brassica napus* L. and thus takes the place of the European types. Colza (*gobhi sarson* or rape) – *Brassica napus* L. is recently introduced from Europe to India.

(B) *Toria* (Indian rape or *lahi* or *maghi lahi*) – *Brassica campestris* L. var. *toria* Duth.

(C) *Rai* (brown mustard or leaf mustard or Indian mustard or *laha* or mustard green or raya) – *Brassica juncea* L. Czern. & Coss.

Two other *rai* crops, viz. *Banarasi rai* (black mustard or true mustard) – *Brassica nigra* Koch. used mainly as spice and *pahadi rai* – *Brassica juncea* var. *rugosa* Roxb. a favourite of *saag* lovers, are also grown to a limited extent.

(D) *Taramira* (*tara* or *duan*) – *Eruca sativa* Mill.

In trade, *sarson*, colza and *toria* are known as rapeseed and *rai* and *Banarsi rai* as mustard. *Taramira* is sometimes erroneously included in rapeseed.

2.2.1 Botanical description

Mustard is an erect, much-branched annual herb. In general, roots are long and tapering. The height of the stem varies from 1.0 to 1.8 m. The stem branches from the axils of the fourth or fifth leaf upwards. The angle at which the branches arise varies with different types. In the shorter varieties, the branches arise at an angle of about 30° to 40° and the plant is more or less dichotomously branched while, in the tall varieties, the branches arise laterally at an angle of 10° to 20° and the plants are tall and appressed. The leaves are stalked and are about 15 to 30 cm long. The basal leaves with a large round terminal lobe are larger than the upper leaves and are lyrately lobed or divided. The leaf colour is generally bright green. The inflorescence is corymbose raceme. The sepals are united, glaucous and

green and turn yellow before falling. The colour of the petals is pale yellow, yellow or cream. The stamens are tetradynamous. The flower bears a hypogynous syncarpous ovary. The ovary is bicarpellary with a large number of ovules and parietal placentation. The fruit is siliqua (pod) 1.5 to 6.5 cm long, strongly ascending or erect with short and stout beaks. The pods are bilocular with a false septum between the two locules. The seed colour is brown or dark brown (Singh, 1958; Anonymous, 1988; Reddi and Reddy, 2003).

2.2.2 Classification

According to the system of classification given by Bentham and Hooker (1862-1883), the aforesaid oil producing species could be classified as follows :

Kingdom	-	Plant kingdom
Division	-	Phanerogamia
Sub-division	-	Angiospermae
Class	-	Dicotyledons
Sub-class	-	Polypetalae
Series	-	Thalamiflorae
Order	-	Parietales
Family	-	Cruciferae
Genus	-	*Brassica*

However, it may be added that the current name of the family is Brassicaceae (Cronquist, 1981) and the recent classification is therefore:

Kingdom	-	Plantae
Subkingdom	-	Tracheobionta

Superdivision	-	Spermatophyta
Division	-	Magnoliophyta
Class	-	Magnoliopsida
Subclass	-	Dilleniidae
Order	-	Capparales
Family	-	Brassicaceae
Genus	-	*Brassica*

2.2.3 Origin

Mustard has been mentioned by ancient Greek writers and appears to have been used by them in medicine.

Prain in 1898 pointed out that *rai* (*Brassica juncea* L.) found its way into India from China through a north-eastern route and its immigration to India has been independent of any *Aryan* incursion. Sinskai in 1928 showed that the native continent of *rai* is Asia, the centre of diversity of forms being China. It is also cultivated in Afghanistan. Vivilov and Buknich in 1929, after making a comparative study of various Afghanistan mustard types, concluded that *Brassica juncea* L. found its way into Afghanistan from India. These opinions point to the conclusion that *Brassica juncea* L. was originally introduced from China into north-eastern India, wherefrom it generally extended to Afghanistan via the Punjab (Singh, 1958; Anonymous, 1988; Reddi and Reddy, 2003).

2.2.4 Distribution

The crop is grown both in subtropical and tropical countries. In Asia, it is chiefly grown in China, India and Pakistan. It is also grown to some extent in Europe and Russia but the forms of oleiferous *Brassiceae*

grown in Europe and Russia are different from those grown in India where the chief producer states are Assam, Bihar, Haryana, Madhya Pradesh, Orissa, Punjab, Rajasthan, Uttar Pradesh and West Bengal (Anonymous, 1988, Reddi and Reddy, 2003).

2.2.5 Climate and soil

Mustard is grown in India as a 'rabi' (winter) crop. It requires somewhat cool climate for satisfactory growth. Since frost arrests the development of seed, it is usually sown earlier than other winter oilseed crops. They grow well in areas having 25 to 40 cm of rainfall. Mustard may be grown on all types of soils (Anonymous, 1988; Reddi and Reddy, 2003).

2.2.6 Cultivation

Mustard is commonly sown mixed with other crops like wheat, barley and gram. Mixed cropping is common in Uttar Pradesh.

A fine seed-bed is required to ensure good germination. Sowing of seeds in excess moisture should be carefully avoided. The seed rate in the case of mixed cropping depends on the proportion of the mustard seed to the main crop. When sown pure, 5 kg/ha seed is used.

The actual time of sowing depends upon the place the crop occupies in rotation. The optimum time for sowing is from 30 September to 15 October. Sowing done later than this gives decreased yields (Reddi and Reddy, 2003).

2.2.7 Harvesting and threshing

The crop is generally harvested when the pods turn yellow but are not fully ripe, as at the later stage the fruits shatter and the seeds disperse.

Also, the moisture content of the seeds should be around 40-45 per cent. The oil content is maximum at this stage.

The harvesting of the crop is done by means of hand operated sickles. The crop is made into bundles and stacked in the sun for a couple of days. Then it is threshed by beating the seed bearing parts of the plants taken in convenient sized bundles, by means of a wooden mallet. Threshing is very easily done as the pods shatter readily and release the seed. The threshed seeds are separated from the husk with the help of natural air current by slowly dropping the threshed produce from the baskets held shoulder high, on to the floor. The threshed grain may then be dried in the sun for another couple of days and then stored in seed bins or gunny bags. The storage room should be completely free from humidity (Singh, 1958; Anonymous, 1988; Reddi and Reddy, 2003).

2.2.8 Uses

The utility of mustard has been pointed out as an article of diet, medicine and industry. The leaves of young plants are used as green vegetable. The plants are also used as green fodder for cattle. The seeds and oil are used as condiment in the preparation of pickle and for flavouring curries and vegetables. The chief use of the oil in India is for edible purposes. The cake and meal left after extraction of oil is rich in protein (30-35%) and is used as animal feed (Singh, 1958; Kaushik *et al.*, 2003).

The seeds and oil have multiple uses in health care systems. The seeds cure 'vata' and 'kapha' ailments of body very effectively. These improve body complexion and remove unwanted fluid and thus help in curing various skin disorders. The inclusion of seeds in cattle feed is

reported to be cooling, digestive and preventive for skin diseases. The oil has antifungal property, which makes it a valuable for massage and control of skin diseases. The oil with garlic and turmeric is used for rheumatism and joint pains. The oil is also used as mosquito repellent. This property is of importance for our country as recurrence of malaria is responsible for innumerable deaths annually. The oil possesses rubefacient properties, it is employed as liniment for rheumatic pains and as a substitute for camphorated oil. In mild bronchitic infections in children, it is used as mild counter irritant on the chest. It helps in removing the pyrrohea when kept in mouth. It strengthens the gums if taken with salt and alum. It helps in healing the wounds by stopping the pus formation (Singh, 1958; Kaushik *et al.*, 2003).

The oil is used for production of confectionery fat, cocoa-butter substitutes and in ice-creams. Some mustard oil is used in the manufacture of *vanaspati.* The most important technical use of the oil is in the manufacture of lubricant additives. The oil is used for quenching steel plates and for the manufacture of soft soap used in sizing cloth. It is also used in production of specialized inks and varnishes. Erucic acid the major fatty acid present in oil (40-45%) has immense industrial applications. Erucic acid is precursor of various chemicals out of which erucamides are very important. Erucamide, a nitrogen derivative of erucic acid is used, among others, in the processing of plastic films, as an antisticking lubricant, manufacturing printing inks (as a dispersing agent). It is also used in high grade lube oil, dispersants, waterproof and antifog agent for paper making and textiles industries, foam stabilizer and metal-wire drawing lubricant

agent. Inferior grades of the cake are used as a manure (Singh 1958; Anonymous, 1988; Singh and Yadav, 2003).

2.3 Phytohormones

The term phytohormone was coined by Thimann in 1948 who defined it as "an organic compound produced naturally in higher plants controlling growth or other physiological functions at a site remote from its place of production and active in minute amounts" (Sinha, 2004). The definition states that a hormone must be translocated in the plants, but nothing is said about how or how far; nor does this mean that the hormone will not cause a response in the cell in which it is synthesized, e.g. ethylene and fruit ripening (Salisbury and Ross, 1992). Phytohormones include growth promoting and growth retarding substances along with flowering, wound healing and vitamin substances oftenly effective at internal concentrations near 1 μM (Salisbury and Ross, 1992; Sinha, 2004). In general, there are five classes of phytohormones. These include auxins, gibberellins, cytokinins, abscisic acid and ethylene. Of these, auxins, cytokinin and gibberellins have growth promotive effect and the abscisic acid and ethylene are growth inhibitory (Devlin and Witham, 1986).

2.3.1 Auxins

These are organic substances having an unsaturated ring to which a carboxylic group is attached with the help of at least one carbon atom. They promote growth along the longitudinal axis, when applied to shoot of plants freed as far as placing from their own inherent growth promoting substances.

2.3.2 Gibberellins

These substances, having gibbane ring skeleton, regulate dormancy, flowering and fruit setting. They stimulate germination of seeds and extend growth of shoots.

Gibberellins were discovered by a Japanese plant pathologist Kurosawa in 1926. While working in the rice fields, Kurosawa found that some rice seedlings grew much taller than the others and such plants were observed to be infected by a fungus *Gibberella fujikuroi*. These seedlings could not support themselves and eventually died from combined weakness and parasite damage. Kurosawa in 1926 further suggested that the growth of rice seedling is stimulated by an active principle toxin. Yabuta in 1935 assigned the name gibberella to the active principle. Thereafter, Yabuta and Sumiki in 1938 isolated and crystallized two biologically active substances – gibberellins A and B. Scientists of England in 1954 named the culture filterate as gibberellic acid and of US as gibberellin X. Later, both the names were universally accepted as gibberellic acid which is now known as GA_3 (Fig. 1). At present, the number of gibberellins known from all sources, including plants is 125. They differ from one another by the presence or absence of the lacton configuration (internal ester) in the ring A and the substituents, mainly hydroxyl groups, about the whole ring structure. Due to presence of an additional ethylenic double bond in ring A, GA_3 is more unsaturated and, thereby, more active than other gibberellins (Salisbury and Ross, 1992; Buchanan *et al.*, 2000; Kumar and Purohit, 2003; Sinha, 2004; Singh, 2005).

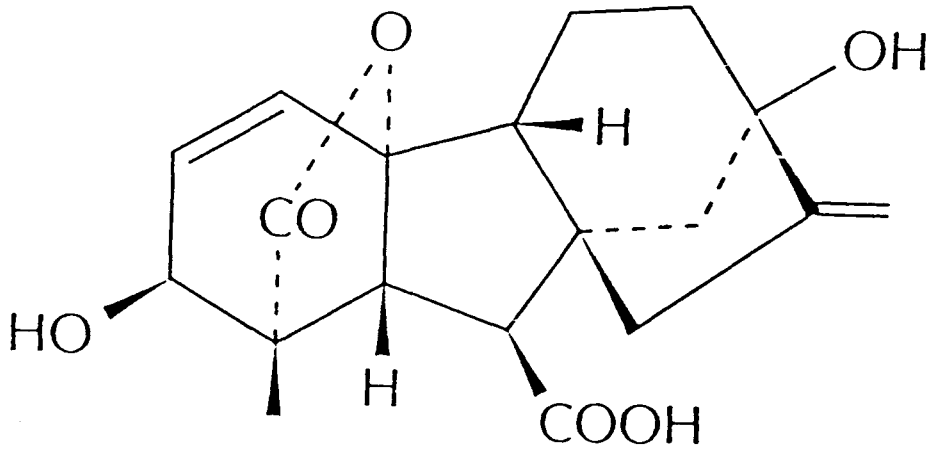


Fig. 1 : Structure of gibberellic acid

GA_3, like other gibberellins, plays an important role in, among others, shoot elongation, genetic dwarfism, germination of seed, breaking dormancy of buds, induction of flowering, parthenocarpy and prevention of senescence. It is also used in floriculture, horticulture and pathogen and insect control.

2.3.3 Cytokinins

These are substances composed of hydrophilic group of higher specificity (adenine) and one lipophilic group without specificity. The cytokinins have similar effects as gibberellins in breaking the dormancy of a wide range of seeds and in increasing fruit set. These hormones mainly stimulate cell divisions and prevent chlorophyll degradation.

2.3.4 Abscisic acid

It is a sesquiterpene and is involved in abscission of plant organs, induction of vegetative buds, regulation of fruit ripening and generally reduction of growth.

2.3.5 Ethylene

It is the only gaseous hydrocarbon hormone which plays an important role, among others, in the ripening of fruit, inhibition of growth and abscission of plant organs.

2.4 Mineral nutrition

The importance of adding plant ash or lime to soil to improve plant growth has been known for more than 2000 years (Marschner, 2002). However, the first evidence of research of plant nutrition dates back to 1656 when Glauber obtained saltpetre from cattle manure and found that it had

great stimulating effect on plant growth. Later, John Woodward in 1699 observed that plants can thrive and grow better in muddy water than clear rain water. But the true role of mineral matter in plant growth was established by de Saussure in 1804. Others, who contributed extensively to this important discipline in the nineteenth century, included Liebig, Pfeffer, Sachs, Knop, Lawes and Gilbert and Bousingault (Bould, 1963).

About 1860, attempts made by Pfeffer, Sachs and Knop resulted in the establishment of essentiality of ten elements, viz. carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), sulphur (S), magnesium (Mg) and iron (Fe). These elements (except Fe) are required in large quantity (1000 mg/kg of dry matter, or more) and constitute the category of macro-nutrients. Later, using techniques to purify salts and the water for hydroponic cultures, plant scientists were also able to establish the essentiality of seven other elements. These include boron (B), chlorine (Cl), copper (Cu), manganese (Mn), molybdenum (Mo), nickel (Ni) and zinc (Zn). Since these elements (and Fe) are required in minute amount (equal to or less than 100 mg/kg of dry matter) they fall in the category of micro nutrients (Salisbury and Ross, 1992; Marschner, 2002).

2.4.1 Nitrogen

Depending on the plant species, developmental stage and organ, the N content required for optimal growth varies between 2 and 5% of the plant dry weight. Nitrate and ammonium ions are the major sources of inorganic nitrogen taken up by the roots of higher plants. Most of the ammonium has to be incorporated into organic compounds in the roots, whereas nitrate is

readily mobile in the xylem and can also be stored in the vacuoles of roots, shoots and storage organs (Marschner, 2002).

It is one of the more important plant nutrients as it is an integral part of amino acids, proteins, coenzymes, porphyrins, purines, pyrimidines, chlorophyll, some vitamins and growth hormones (Devlin and Witham, 1986). It encourages the vegetative development of the plant by imparting a healthy green colour to the leaves. It also controls, to some extent, the efficient utilization of P and K. Its deficiency retards growth and root development, turns the foliage yellowish or pale green, hastens maturity, causes the shrivelling of grains and lowers crop yield. The older leaves are affected first (Patnaik, 2003).

Plant grown with excess nitrogen usually have dark green leaves and show an abundance of foliage, usually with a root system of minimal size and, therefore, a high shoot-to-root ratio. Its excess also delays the maturation of plants and increases susceptibility to diseases (Salisbury and Ross, 1992; Patnaik, 2003).

2.4.2 Phosphorus

The P requirement for optimal growth is in the range of 0.3-0.5% of the plant dry matter (Marschner, 2002). It is absorbed primarily as the monovalent phosphate anion $H_2PO_4^-$ and less rapidly as the divalent anions HPO_4^{2-}. The soil pH controls the relative abundance of these two forms, $H_2PO_4^-$ being favoured below pH 7 and HPO_4^{2-} above pH 7. Phosphate is easily redistributed and much phosphate is converted into organic forms upon entry into the root or after transport through the xylem into the shoot (Salisbury and Ross, 1992).

It is an essential part of many sugar phosphates involved in photosynthesis, respiration and other metabolic processes, and it is also part of the nucleotides DNA and RNA and of the phospholipids present in membranes. It also plays an essential role in energy metabolism because of its presence in ATP, ADP, AMP and PPi. It influences the vigour of plants and improves the quality of crops. It encourages the formation of new cells, promotes root growth (particularly the development of fibrous roots) and hastens leaf development, the emergence of ears, the formation of grains and the maturation of crops. It also increases resistance to diseases and strengthens the stems of cereal plants, thus reducing their tendency to lodge. If phosphorus is deficient in the soil, plants fail to make a quick start, do not develop a satisfactory root system, remain stunted and sometimes develop a tendency to show a reddish or purplish discolouration of the stem and foliage owing to an abnormal increase in the sugar content and the formation of anthocyanins, the older leaves being affected first (Salisbury and Ross, 1992; Patnaik, 2003).

If excess P is provided, root growth is often increased relative to shoot growth. This is in contrast to the effect of excess nitrogen and causes low shoot-to-root ratio (Salisbury and Ross, 1992).

2.4.3 Potassium

The K requirement for optimal plant growth is in the range of 2-5% of the plant dry weight. It is a univalent cation. It is characterized by high mobility in plants at all levels – within individual cells, within tissues and in long distance transport via the xylem and phloem (Marschner, 2002).

Opposed to N and P, K is not an incorporated component of plant molecules. It is an activator of more than 60 enzymes that are essential for photosynthesis, respiration and formation of starch, proteins, nucleotides etc. (Evans and Sorger, 1966; Wallingford, 1980; Bhandal and Malik, 1988; Imas, 1999; Marschner, 2002). It plays an important role in opening and closing of stomata and translocation of sugars (Marschner 2002; Patnaik, 2003). It has also a motor function in cycling nutrients for growth, i.e. N from roots to shoot and C from source to sink (Krauss, 2001). It enhances the ability of plants to resist diseases, insect attacks, cold and other adverse conditions.

Lack of K restricts the NO_3 transport, which leads to nitrate reduction and accumulation of amino acids in roots. The plant cannot be forced to take up additional N if K is in short supply (Krauss, 2001). Its deficiency also produces mottled or chlorotic leaves with large or small spots of dead tissue. The older leaves are affected first (Salisbury and Ross, 1992; Patnaik, 2003).

An excess of the element tends to delay maturity, though not to the same extent as that of N. Plants can take up and store K in much larger quantities than what is needed for optimum growth and this excess uptake is known as luxury consumption (Patnaik, 2003).

2.4.4 Calcium

The Ca content in plants varies between 0.1 and >5.0% of dry weight (Marschner, 2002). Ca is absorbed as bivalent cation. It is the most immobile of the essential elements (Gardner *et al.*, 2003).

It is a critical part of the cell wall that produces strong structural rigidity by forming cross link within the pectin polysaccharide matrix (Easterwood, 2002). It is also found as Ca-oxalate and Ca-carbonate in the vacuoles; these salts supposedly immobilize the constituent organic acid to non-toxic level (Gardner *et al.*, 2003). It is a constituent of arginine kinase, adenosine triphosphatase, adenyl kinase, potato apyrase and α-amylase (which is synthesized on the rough endoplasmic reticulum). It also stimulates a range of membrane-bound enzymes (Rensing and Cornelius, 1980), particularly ATPase at the plasma membrane of roots of certain plant species (Kuiper and Kuiper, 1979). It plays a key role in signal conduction, osmoregulation and cation-anion balance by acting as counterion for inorganic and organic anions (Kinzel, 1989; Marschner, 2002). Ca also promotes the activity of soil bacteria concerned with the fixation of free nitrogen or the formation of nitrates from organic forms of nitrogen. Furthermore, it promotes plant growth by rendering more soluble some of the insoluble salts of other nutrients resulting from the base exchange action (Patnaik, 2003).

Deficiency symptoms are always more pronounced in young tissues (Kirkby and Pilbeam, 1984). Meristematic zones of roots, stems and leaves, where cell divisions occur, are most susceptible. Twisted and deformed tissues result from Ca deficiency and the meristematic zone dies early. Mottled discolouration of the leaves and the death of the tissues are other symptoms of extreme Ca insufficiency. Since Ca deficiency is commonly associated with acidity and the accompanying accumulation of soluble toxic salts of Fe, Al and Mn, the ill effects shown by the plants may be due to

acidity or toxicity of one or another compound of these elements (Salisbury and Ross 1992; Patnaik,2003).

An excess of Ca retards some plant diseases. Fungal pathogenic infection is reduced with increased Ca uptake by plant (Easterwood, 2002; Patnaik, 2003).

2.5 N, P, K and Ca containing fertilizers

Continuous cultivation, leaching, immobilization, denitrification, fixation and volatilization result in soil nutrient losses. To overcome the affected nutrient supplying power of the soils and to get high yields, plant nutrients must be added. The important sources of N, P, K and Ca are given below.

Nitrate, anhydrous ammonia, ammonium salts and urea are the more common forms of N fertilizers. Single superphosphate, triple superphosphate, nitric phosphate and ammonium polyphosphate are the major P fertilizers. Muriate of potash (potassium chloride) and sulphate of potash (potassium sulphate) are the principal K fertilizers. Main sources of Ca comprise lime, calcite, dolomite, gypsum, any phosphorus fertilizer, anorthite, biotite, apatite, augite and hornblende (Tisdale *et al.*, 1993; Patnaik, 2003).

2.6 Methods of phytohormone and nutrient application

In nature, phytohormones required for growth and development are synthesized in plants themselves. However, they could be added exogenously to exploit the full genetic potential of plants. Generally, the hormones are supplied to plants via pre-sowing seed treatment or through

foliar application as dilute solutions at crucial stages (Ahmad *et al.*, 2001; Hayat *et al.*, 2002; Khan and Samiullah, 2003).

Nutrients are absorbed by plants generally through their root system from the soil. They can be applied to the soil by various ways. These include gaseous application, applying nutrients in irrigation water, banding, broadcasting, strip placement, top-dressing and side-dressing (Donahue *et al.*, 1990). However, to obtain maximum nutrient use efficiency or under conditions when soil application is not feasible, nutrients are applied to the plants through foliage in the form of dilute aqueous solutions (Mengel and Kirkby, 1996; Marschner, 2002)

2.7 Response of mustard to phytohormone and nutrient application

Considerable literature is available on the effect of exogenous application of nutrients on the performance of mustard and its allies but the same is not true for GA_3. However, much of it is antiquated, being based on relatively low-yielding varieties that have since been replaced by improved new ones. In view of this, an effort has been made in the following pages to review the available literature published during the last two decades only. Moreover, as the present study was planned to be carried out in India, most of the references included are of Indian origin.

Mehta and Saran (1986), working on *Brassica juncea* variety BR-23 at Patna (Bihar), studied the effect of pre-sowing soaking treatment in 10 and 100 ppm IAA, GA_3 and 2,4,5-T on N and oil content of subsequently produced seeds. They reported that, of the six treatments tried, only GA_3 at 100 ppm improved the seed quality in terms of the above parameters.

Mohammad *et al.* (1986) performed a field experiment at Aligarh (U.P.) on ten high yielding varieties of mustard (*Brassica juncea* L. Czern. & Coss.), namely Appressed Mutant, Pusa Kisan, Pusa Kranti, R.75-2, RIK-3, RL-18, RS-3, T-11, T-16 and Varuna. They were grown with a uniform basal dose of 60 kg N + 40 kg P_2O_5 (17.5 kg P) + 40 kg K_2O (33.2 kg K)/ha and were sprayed with 20 kg N + 8 kg P_2O_5 (3.5 kg P) + 2 kg S/ha in two equal splits at 70 and 90 days. The data revealed that varieties, R.75-2, RL-18, RS-3 and Varuna performed better. All four varieties proved at par in giving maximum oil yield. R.75-2 (equalled by Varuna) and RS-3 gave maximum yield and oil content of seed, respectively.

Vasi *et al.* (1986), carrying out a field experiment at Pantnagar (Uttaranchal), studied the performance of four varieties of Indian rape (*Brassica campestris*), namely PT-30, PT-303, Sangam, T-9, grown with a uniform basal dose of 60 kg N + 40 kg P_2O_5 (17.5 kg P) + 20 kg K_2O (16.6 kg K)/ha. They found that variety PT-303 performed best.

Chaturvedi *et al.* (1988) performed a varietal trial in the field on fifteen varieties of Indian mustard (*Brassica juncea* L.), namely B-85 and K-1 (early types), Pusa Kisan, RLM-198, RLM-528, RS-3, RT-16, T-5909 and Varuna (medium types) and Prakash, Pusa Bold, Pusa Kranti, RH-30, RT-11 and Varanasi Local (late types), at Faizabad (U.P.). They applied a uniform basal dose of 80 kg N, 40 kg P_2O_5 (17.5 kg P) and 40 kg K_2O (33.2 kg K)/ha. Of early types, K-1 and among medium types RT-16 and Varuna (being at par in seed yield) proved better. As far as late types were concerned, Prakash and Pusa Bold, being at par in producing seeds, proved superior.

Khan *et al.* (1990) conducted a field experiment on six varieties of mustard (*Brassica juncea* L.), viz. KRV-47, Pusa Bold, PR-18, RK-1467, RK-8201 and Varuna, at Aligarh (U.P.). They applied four basal combinations of N and P, i.e. 60 kg N + 20 kg P/ha ($N_{60}P_{20}$), 60 kg N + 30 kg P/ha ($N_{60}P_{30}$), 90 kg N + 20 kg P/ha ($N_{90}P_{20}$) and 90 kg N + 30 kg P/ha ($N_{90}P_{30}$) with a uniform dose of 30 kg K/ha. They noted that yield and its attributing characters were increased maximally by $N_{60}P_{20}$. For oil quality, minimum iodine value and maximum saponification value were noted with $N_{60}P_{30}$ and $N_{60}P_{20}$ respectively. Regarding varieties, Varuna proved better than the others for all parameter studied. For nutrient and variety interactions, $N_{60}P_{30}$ x Varuna gave maximum seed and oil yield.

Saran and Giri (1990) layed out a field experiment on mustard (*Brassica juncea* L.) variety Pusa Barani at New Delhi to study the effect of five combinations of N and P, i.e. 0 kg N + 0 kg P/ha (N_0P_0), $N_{40}P_{11}$, $N_{40}P_{22}$, $N_{80}P_{11}$ and $N_{80}P_{22}$, on its performance. Results revealed that application of $N_{40}P_{11}$ increased seed yield over N_0P_0. Additional 40 kg N/ha further increased the seed yield.

Sharma and Kamath (1990), conducting a pot experiment at New Delhi, studied the effect of three levels each of P (0, 8.8 and 17.5 mg P/kg soil) and Ca (0, 20.1 and 40.2 mg Ca/kg soil) on dry matter yield and P uptake in mustard (*Brassica juncea* L.) variety Pusa Bold. They reported that dry matter and P uptake were increased by P application up to 17.5 mg P/kg soil and by Ca application up to 20.1 mg Ca/kg soil.

Rathore and Manohar (1990), conducting a field experiment at Jobner (Rajasthan) on mustard (*Brassica juncea* L.), studied the effect of

seven levels of N (0, 30, 60, 90, 120, 150 and 180 kg N/ha) on seed yield and N uptake. They found that there was an increase in seed yield and N uptake with increasing levels of N up to 120 kg N/ha.

Agarwal and Gupta (1991), laying out a field experiment at Udaipur (Rajasthan), studied the effect of 3 levels of N (0, 30 and 60 kg N/ha), and two levels of P, i.e. 0 and 30 kg P_2O_5 (0 and 13.1 kg P)/ha on mustard (*Brassica juncea* L.) variety Varuna. They reported that growth and seed and oil yield increased with increasing levels of N. However oil content was adversely affected by N application. As far as the effect of P was concerned, application of 13.1 kg P/ha proved better.

Bharadwaj (1991) conducted a field experiment at Gwalior (M.P.) to evaluate the performance of three varieties of mustard (*Brassica juncea* L.), namely Kranti, Pusa Bold and Varuna at four rates of N (0, 30, 60 and 90 kg N/ha). They reported that N application significantly increased the seed yield linearly up to 90 kg N/ha. Variety Varuna, possessing branches as well as pods per plant, gave significantly higher seed yield than Kranti.

Parihar (1991), carrying out a field experiment at Kharagpur (West Bengal), studied the effect of three levels of N (30, 60 and 90 kg N/ha) on yield of mustard (*Brassica juncea* L.) variety T-59. He noted significant increase in grain yield only up to 60 kg N/ha.

Rana *et al.* (1991), performing a field experiment at Baraut (U.P.), studied the effect of four levels of N (0, 50, 100 and 150 kg N/ha) on N content and uptake as also oil content and yield of mustard. They noted that increasing levels of N enhanced the content and uptake of N and oil yield linearly but decreased oil content.

Singh *et al.* (1991), conducting a field experiment at Varanasi (U.P.), studied the effect of four levels of N (0, 25, 50 and 75 kg N/ha) and 3 levels of P, i.e. 0, 20 and 40 kg P_2O_5 (0, 8.7 and 17.5 kg P)/ha on growth and yield attributes of mustard (*Brassica juncea* L.) variety Varuna. They reported that increasing levels of N or P significantly increased plant height, number of branches, pods per plant, seeds per pod, 1000-seed weight and seed yield. Whereas N application decreased the oil content in mustard seed. P application did not affect the oil content.

Singh and Kumar (1991), conducting a field trial at Pantnagar (Uttaranchal), studied the effect of 0 (water), 1 and 10 ppm GA_3 spray on yield and yield attributes of mustard (*Brassica juncea* L. variety not mentioned). Application of GA_3 spray at 10 ppm proved better for branches per plant, pods per plant and seed yield per plant.

Mohammad (1992) conducted a field experiment at Aligarh (U.P.) to study the combined effect of soil-applied (40 kg N + 10 kg P, 30 kg N + 7.5 kg P and 20 kg N + 5 kg P/ha) and leaf-applied (water, 10 kg N + 2.5 kg P and 20 kg N + 5 kg P/ha) nutrients in the presence of a uniform dose of 15 kg K/ha on two rainfed varieties (RK-9 and RK-1418) of mustard (*Brassica juncea* L.) under rainfed conditions. The nutrient solution was sprayed in two equal splits, i.e. half at 70 days and the remaining half at 90 days. Treatment $B_{N30P7.5}$ and $F_{N10P2.5}$ and variety RK-1418, alone as well as in combination, proved best, with $B_{N30P7.5}$ and $F_{N10P2.5}$ x RK-1418 registering 40.0% more seed yield and 37.9% more oil yield than $B_{N40P10}+F_w$ x RK-9 that gave the lower values.

Prasad and Shukla (1992), carrying out a field experiment at Varanasi (U.P.), studied the effect of combined application of three levels each of N (0, 40 and 80 kg N/ha) and K, i.e. 0, 30 and 60 kg K_2O (0, 24.9 and 49.8 kg K)/ha, on N, P and K accumulation in mustard (*Brassica juncea* L. variety not mentioned). They reported that 80 kg N + 49.8 kg K/ha significantly increased N, P and K accumulation in plants.

Saran *et al.* (1992), carrying out an experiment at Patna (Bihar), studied the effect of pre-sowing seed treatment with GA_3 (0, 25, 50, 75 and 100 ppm GA_3) on growth, yield and chlorophyll content of mustard (*Brassica juncea* L.) variety BR-23. They reported that pre-sowing seed treatment with GA_3 increased shoot length, internode length and fresh and dry weights. Seed weight also increased at 50 ppm and above. They also reported that increase in total chlorophyll content at higher concentrations (75 and 100 ppm) of GA_3 was mainly due to increased chlorophyll b content.

Subrahmanyam and Rathore (1992), conducting a pot experiment at Pantnagar (Uttaranchal), studied the effect of four levels of foliar spray of GA_3 (0, 10, 50 and 100 ppm GA_3) on $^{14}CO_2$ assimilation, partitioning of ^{14}C into major biochemical fractions and translocation of assimilates in different parts of mustard (*Brassica juncea* L.) variety Krishna. They reported that leaves, stem and pod walls were photosynthetically active and were important sources for seed filling. Data revealed that GA_3 increased the export of $^{14}CO_2$ assimilates out of source organs and increased the movement of assimilates into the reproductive parts (pods). They suggested that the increased movement of photoassimilates into the developing pods

might be due to the stimulation of sink activity by the growth regulator which resulted in higher demand for photoassimilates. They also suggested that the growth regulator might increase yield by altering distribution of assimilates in the mustard plants.

Tomer *et al.* (1992a), performing a field experiment at Hardwar (Uttaranchal), studied the effect of four levels of fertilization [(no fertilizer, 40 kg N + 20 kg P_2O_5 (8.7 kg P) + 20 kg K_2O (16.6 kg K), 80 kg N + 40 kg P_2O_5 (17.5 kg P) + 40 kg K_2O (33.2 kg K) and 120 kg N + 60 kg P_2O_5 (26.2 kg P) + 60 kg K_2O (49.8 kg K)/ha] on growth and yield of mustard (*Brassica juncea* L.) variety Varuna. They reported that growth, yield attributes and yield increased significantly with an increase in the level of NPK. Number of branches, dry matter accumulation per plant and seed yield per hectare were maximum with 120 kg N + 26.2 kg P + 49.8 kg K/ha. Oil yield was found to be maximum with 80 kg N + 17.5 kg P + 33.2 kg K/ha, whereas oil content was highest with no fertilization. Tomer *et al.* (1992b) further reported on the basis of the same experiment that increasing levels of fertility up to the highest level increased the N and P uptake both in seed and stover of mustard.

Grewal *et al.* (1993), conducting a field experiment at Ludhiana (Punjab), studied the response of *Brassica napus* L. (Gobhi sarson) to N application (0, 50 and 100 kg/ha) in the presence of a uniform dose of 24 kg P/ha. They reported that plant height, leaf area index, chlorophyll content, interception of photosynthetically active radiation, pods per plant, seeds per pod and seed yield increased with increasing levels of N. 1000-seed weight was reported to be maximum with 50 kg N/ha. However, the effect was at

par with that of 0 kg N/ha; but N application did not affect the oil content of the seeds.

Prasad and Shukla (1993), carrying out a field experiment at Varanasi (U.P.), studied the interaction effect of N and K on the performance of mustard (*Brassica juncea* L.) variety T-59. They applied N at 0, 40 and 80 kg N/ha and K at 0, 30 and 60 kg K_2O (0, 24.9 and 49.8 kg K)/ha. They reported that application of 80 kg N/ha in combination with 49.8 kg K/ha proved best for plant height, number of leaves, number of branches, leaf area and grain yield of the crop.

Sarma and Roy (1993), conducting an experiment at Diphu (Assam), studied the performance of eight varieties of Indian mustard (*Brassica juncea* L.), viz. Dira-367, Kranti, Krishna, RH-30, RH-781, TM-2, TM-4 and Varuna. They reported that variety Dira-367, followed by Varuna and TM-4, gave the highest seed yield. Varieties TM-2 and RH-781 showed below-average response.

Sharma (1993), carrying out a field experiment at Gwalior (M.P.), studied the performance of four varieties of mustard (*Brassica juncea* L.), namely Kranti, Krishna, Pusa Bold and Varuna. They observed that variety Kranti gave maximum seed yield. It was followed by Pusa Bold which was at par with Varuna. Variety Krishna proved a poor yielder.

Shukla and Kumar (1994), conducting a field experiment at Pantnagar (Uttaranchal), studied the effect of four levels of N (0, 40, 80 and 120 kg N/ha) along with a uniform dose of 20 kg P_2O_5 (8.7 kg P) + 20 kg K_2O (16.6 kg K)/ha on dry matter accumulation, N content, N uptake and seed yield of six varieties of Indian mustard (*Brassica juncea* L.), namely

Kranti, Krishna, Pusa Bold, Rohini, Vardan and Varuna. They noted that increasing levels of N enhanced dry matter accumulation, N content, N uptake and seed yield linearly. They also found that varieties Kranti, Vardan and Krishna, being at par, accumulated more dry matter than the others. N content and uptake were highest in Vardan. However, the seed yield of Vardan, Krishna and Kranti did not differ significantly. Rohini proved poor yielder.

Arthamwar *et al.* (1996) performed a field experiment at Parbhani (Maharashtra) to study the effect of three levels each of N (0, 50 and 100 kg N/ha) and P, viz. 0, 40 and 80 kg P_2O_5 (0, 17.5 and 35 kg P)/ha, on yield attributes and seed and oil yield of four varieties of Indian mustard (Pusa Bold, PR-18, T-59 and Local). They observed that each higher level of N significantly improved all the yield parameters and seed and oil yield. They also reported that N levels did not influence the oil content. However, every increase in the level of P significantly improved all the yield attributes, seed yield, oil content and oil yield. Regarding varietal differences, they added that Pusa Bold had significantly higher values for yield attributes, seed and oil yield than PR-18, T-59 and Local.

Khan (1996) performed a pot experiment on mustard (*Brassica juncea* L.) variety T-59 at Aligarh (U.P.). He sprayed plants with 0, 25 and 50 μM GA_3 at the three fully developed leaf stage, viz. 30 days after sowing (DAS), and studied its effect on carbonic anhydrase activity, photosynthetic rate, leaf area index and dry mass at 50, 70 and 90 DAS. At harvest, 1000-seed mass, pod number and seed yield were also recorded. He reported that spray of 50 μM GA_3 proved best for all the characteristics studied.

Khan *et al.* (1996), conducting a pot experiment at Aligarh (U.P.), studied the effect of three concentrations of N spray (5 mM, 10 mM and 20 mM N) with or without 50 μM GA_3 on carbonic anhydrase and nitrate reductase activities, net photosynthetic rate, leaf area index and dry mass of mustard (*Brassica juncea* L.) variety T-59. They reported that application of 20 mM N inhibited carbonic anhydrase activity, nitrate reductase activity and net photosynthetic rate at 50 DAS. However, when GA_3 was applied in association with the foliar spray of N, the inhibition was reversed and the above parameters, as also leaf area index and dry mass, were enhanced.

Patil *et al.* (1996), laying out a field trial at New Delhi (India), studied the effect of N fertilization (0, 40, 80 and 120 kg N/ha) on yield contributing characters and seed yield of *Brassica juncea* L. variety Pusa Bold and *Brassica campestris* L. variety Pusa Kalyani. They reported that the number of pods and seed yield in the two species were favourably modified by increasing levels of N supply. N treatment showed no significant effect on 1000-seed weight. *Brassica juncea* gave significantly higher yield than *Brassica campestris*.

Tomer *et al.* (1996), working at Baraut (U.P.), applied four levels of fertilization, i.e. no fertilizer, 40 kg N + 20 kg P_2O_5 (8.7 kg P) + 20 kg K_2O (16.6 kg K), 80 kg N + 40 kg P_2O_5 (17.5 kg P) + 40 kg K_2O (33.2 kg K) and 120 kg N + 60 kg P_2O_5 (26.2 kg P) + 60 kg K_2O (49.8 kg K)/ha to four Indian mustard (*Brassica juncea* L.) varieties, namely Prakash, Pusa Bold, RH-8113 and Varuna. The data showed that increasing level of fertilization significantly increased plant height, number of branches, dry matter accumulation per plant, number of pods per plant, 1000-seed weight and

seed and oil yield. They also found that all these growth and yield attributes were significantly higher in Pusa Bold and Varuna than in Prakash and RH-8113. The interaction of Pusa Bold and Varuna with the higher levels of fertilization gave maximum dry matter accumulation per plant and seed yield than RH-8113 without fertilization, which gave the minimum values.

Bora (1997), carrying out an experiment at Jorhat (Assam), studied the effect of three levels of Ca on performance of one variety of Indian mustard (*Brassica juncea* L.), namely Varuna, and two varieties of rapeseed (*Brassica campestris* L.), viz. M-27 and TS-29. He reported that application of Ca increased seed and oil yield, with both 20 and 40 kg Ca/ha remaining at par in their effect. However, seed oil content was not affected due to Ca. They also added that the Indian mustard excelled in seed yield and rapeseed in seed oil content.

Gurjar and Chauhan (1997), conducting a field experiment at Bagwai (M.P.), studied the effect of five fertility levels, viz. 0 kg N + 0 kg P, 25 kg N + 16.6 kg P_2O_5 (7.2 kg P), 50 kg N + 33 kg P_2O_5 (14.4 kg P), 75 kg N + 50 kg P_2O_5 (21.8 kg P) and 100 kg N + 66.4 kg P_2O_5 (29 kg P), on the performance of two varieties of mustard (*Brassica juncea* L.), namely Kranti and Pusa Bold. Application of 75 kg N + 21.8 kg P/ha proved best for height, leaf number, primary and secondary branches, pod number and seed yield. They also found that Pusa Bold and Kranti were at par in yield.

Khafi *et al.* (1997), conducting a field experiment at Udaipur (Rajasthan), studied the effect of five levels of N (0, 20, 40, 60 and 80 kg N/ha) and two levels of P, viz. 0 and 30 kg P_2O_5 (13.1 kg P), on the performance of Indian mustard (*Brassica juncea* L.) variety Kranti. They

reported that application of N significantly increased yield attributes and seed and stover yields up to the highest level (80 kg N/ha). Similarly, application of 13.1 kg P/ha significantly improved these parameters.

Mohammad and Khan (1997) conducted a field experiment at Aligarh (U.P.) on three mustard varieties, viz. Rohini, Vabhav and Varuna, grown with either 60 kg N + 20 kg P or 90 kg N + 30 kg P/ha with N being applied as (i) full basal (B) (ii) 2/3 basal + 1/3 top-dressing (T) or (iii) 2/3 basal + 1/3 foliar (F). They sprayed the plants receiving full basal treatment with deionised water (F_w). A uniform dose of 30 kg K/ha was given at the time of sowing. The top-dressing and spray treatments included application of N in two equal splits at 50 and 70 DAS. They reported that the lower dose of N and P was insufficient for the cultivation of mustard, ruling out the possibility of fertilizer economy for this crop. However, it was established that top-dressing surpassed basal treatment while foliar spray excelled even top-dressing. Foliar spray of 30 kg N/ha on plants grown with 60 kg N and 30 kg P/ha ($B_{N60P30}+F_{N30}$) proved optimum for almost all growth and yield attributing parameters studied. This resulted in an increase in seed and oil yield of 11.8 and 12.1% respectively over the control, i.e. spray of water on plants receiving the officially recommended basal dose (90 kg N + 30 kg P/ha). Rohini performed best among the varieties tested, while the interaction $B_{N60P30}+F_{N30}$ x Rohini proved optimum for most characters.

Sharma *et al.* (1997), conducting a field experiment at Hisar (Haryana), studied the effect of five N levels (no N, seed treatment with *Azotobacter* only, 30, 60 and 90 kg N/ha) on seed yield, oil quality and oil

yield of two varieties of *Brassica juncea* L. (RH-30 and RH-819) and one variety of *Brassica campestris* L., viz. TCH-2. They noted that N application reduced the oil content but improved the protein content of seeds. N treatment significantly increased the seed, oil and protein yield over the control. However, the response was found up to 60 kg N/ha only. N application also increased free fatty acids and iodine number in oil. Regarding varietal differences, TCH-2 had higher oil content and lower protein content than RH-30 and RH-819. Variety RH-30 gave higher seed, oil and protein yield than RH-819 and TCH-2. In terms of oil quality, varieties RH-30 and RH-819 gave relatively higher values for free fatty acids and iodine number.

Tomer *et al.* (1997), performing a field experiment at Gurukul Narsan (U.P.), studied the effect of three levels each of N (60, 120 and 180 kg N/ha) and P, viz. 0, 40 and 80 kg P_2O_5 (0, 17.5 and 35 kg P)/ha, on the performance of Indian mustard (*Brassica juncea* L.) variety Krishna. They noted that plant height, branches per plant, dry matter accumulation per plant, pods per plant, seeds per pod, 1000-seed weight, seed yield and stover yield increased significantly with increasing levels of N and P up to 180 kg N/ha and 35 kg P/ha respectively. The oil content of seeds decreased with the increase in the levels of N and P.

Chanda *et al.* (1998), performing an experiment at Rajkot (Gujarat), studied the effect of GA_3 (10 μM GA_3) given in the nutrient solution on growth and activities of nitrate reductase and glutamine synthetase in seedlings of mustard (*Brassica juncea* L.) variety Varuna. They found that GA_3 promoted nitrate reductase activity in cotyledons and cytosolic

glutamine synthetase activity in root and hypocotyl. However, it was reported that GA_3 treatment inhibited chloroplastic glutamine synthetase.

Puri *et al.* (1999) conducted a field trial on mustard [(*Brassica juncea* L. (variety not mentioned)] at Jabalpur (M.P.). They studied the effect of five levels of N (0, 25, 50, 75 and 100 kg N/ha), four levels of P, viz. 0, 20, 40 and 60 kg P_2O_5 (0, 8.7, 17.5 and 26.2 kg P)/ha, and three levels of K, i.e. 0, 20 and 40 kg K_2O (0, 16.6 and 33.2 kg K)/ha, applied in fractional factorial combination of 21 treatments on nutrient content and uptake, oil content and seed yield of the crop. The maximum N content was noted with 50 kg N + 17.5 kg P + 33.2 kg K/ha, P content with 75 kg N + 26.2 kg P + 0 kg K/ha, K content with 100 kg N + 26.2 kg P + 33.2 kg K/ha, N uptake with 100 kg N + 17.5 kg P + 33.2 kg K/ha, P uptake with 75 kg N + 26.2 kg P + 33.2 kg K/ha, K uptake with 100 kg N + 17.5 kg P + 33.2 kg K/ha, oil content with 25 kg N + 0 kg P + 16.6 kg K/ha and seed yield with 40 kg N + 17.5 kg P + 16.6 kg K/ha.

Singh (1999) performed a field experiment on Indian mustard (*Brassica juncea* L.) variety Varuna at Mainpuri (U.P.). They applied five levels of N (0, 40, 80, 120 and 160 kg N/ha) and three levels of sulphur + calcium, (0 kg S + 0 kg Ca/ha), viz. S_0+Ca_0, S_{25} + Ca_{50} and S_{50}+Ca_{100}. Application of 160 kg N + 50 kg S + 100 kg Ca/ha resulted in maximum seed yield.

Bhari *et al.* (2000), conducting a field experiment at Sri Ganganagar (Rajasthan), studied the effect of N and P on the response of Indian mustard (*Brassica juncea* L.) variety Varuna. They applied four levels each of N (30,

60, 90 and 120 kg N/ha) and P, viz. 0, 15, 30 and 45 kg P_2O_5 (0, 6.6, 13.1 and 19.7 kg P)/ha. They noted that application of N up to 120 kg N/ha resulted in increase in plant height, primary and secondary branches, pods per plant and seed yield. However, seeds per siliqua and 1000-seed weight increased only up to 90 kg N/ha. Application of P up to 19.7 kg P/ha resulted in significant increase in plant height, secondary branches, pods per plant and seed yield. They also reported that the maximum seed yield of Indian mustard was harvestable with the combined application of 120 kg N and 19.7 kg P/ha.

Patidar *et al.* (2000), performing a field experiment at Jodhpur (Rajasthan), studied the effect of three fertility levels [control, 60 kg N + 40 kg P_2O_5 (17.5 kg P)/ha and 60 kg N + 40 kg P_2O_5 (17.5 kg P) + 15 kg S/ha] on growth and productivity of three varieties of Indian mustard (*Brassica juncea* L.), namely Local, Pusa Bold and Varuna. In comparison with the control, application of 60 kg N + 17.5 kg P/ha proved superior for growth, yield and yield attributes. However, response to 60 kg N + 17.5 kg P + 15 kg S/ha was best. Regarding varietal differences, they added that varieties Pusa Bold and Varuna, being at par, were superior to Local variety.

Singh and Prasad (2000), conducting a field experiment at Kanpur (U.P.), studied the effect of three levels of N (60, 120 and 180 kg N/ha) along with a uniform dose of 40 kg P_2O_5 (17.5 kg P) and 40 kg K_2O (33.2 kg K)/ha on yield attributes and yield of mustard (*Brassica juncea* L.) variety Basanti. They reported that application of 120 kg N/ha proved best for branches, siliqua, siliqua weight, seed weight and seed yield.

Khan *et al.* (2001), conducting a field experiment at Aligarh (U.P.), studied the effect of four basal doses of Ca (0, 20, 40 and 60 kg Ca/ha) as $CaSO_4.2H_2O$ in the presence of 90 kg N + 30 kg P + 30 kg K/ha on growth and yield performance of mustard (*Brassica juncea* L.) variety Varuna. In general, 40 kg Ca/ha gave maximum values for growth and yield parameters.

Kumar *et al.* (2001) laid down a field experiment on five varieties of Indian mustard (*Brassica juncea* L.), namely CS-52, GJM-9056, Kranti, RH-30 and RH-8814 and one variety of Swede rape (*Brassica napus* L.), i.e. GSH-1 at Hisar (Haryana), applying four levels of N (0, 40, 60 and 80 kg N/ha). They found that increasing levels of N up to 60 kg N/ha enhanced total dry matter whereas 80 kg N/ha, seed yield and harvest index. Variety RH-8814 was superior to other varieties, including GSH-1, for dry matter production. Moreover, there was no significant differences in seed yield among *Brassica juncea* L. varieties. However, they were significantly superior to *Brassica napus* L. Variety RH-30 gave better harvest index than others.

Khan *et al.* (2002), in a field trial at Aligarh (U.P.), examined the effect of foliar spray of three levels (0, 10^{-6}, 10^{-5} and 10^{-4} M) each of indole acetic acid (IAA), GA_3 and kinetin (Kn) on growth and yield characteristics of mustard (*Brassica juncea* L.) variety Varuna. They reported that GA_3 application at 10^{-5} M concentration was found to be more effective than IAA and Kn in promoting shoot length, leaf number, leaf area, dry weight, net assimilation rate and seed yield.

Singh and Singh (2002), laying out a field experiment at Faizabad (U.P.), studied the effect of five doses of N (0, 40, 80, 120 and 160 kg N/ha)

on the performance of two varieties of Indian mustard (*Brassica juncea* L.), viz. Vardan and Varuna. They reported that growth characters, yield attributes, yield and quality (seed protein content) increased with successive increase in N up to 120 kg N/ha. Regarding varietal differences, they added that variety Varuna gave higher values than Vardan for growth characters, yield attributes, yield and quality.

Singh *et al.* (2002), conducting a field experiment at Pantnagar (Uttaranchal), studied the effect of four fertility levels (50%, 75%, 100% and 125%) of the recommended dose, viz. 60 kg N + 40 kg P_2O_5 (17.5 kg P) + 20 kg K_2O (16.6 kg K)/ha, on yield attributes, seed yield, harvest index, oil content and oil yield of two varieties each of *Brassica juncea* L. (PR-8988 and Kranti) and *Brassica carinata* Braun (DLSC-1 and PBC-9221). They reported that the successive increase in fertility levels enhanced N content and uptake, yield attributes, seed yield and oil yield. However, application of fertility resulted in a decrease in oil content.Regarding varietal differences, they added that PBC-9221 gave higher values for yield and yield attributes. Oil content was higher in Kranti and harvest index in both Kranti and PR-8988.

Khan and Samiullah (2003) conducted a field experiment at Aligarh (U.P.) to compare the effect of two modes of GA_3 application (seed soaking or foliar spray) at 0, 10^{-6}, 10^{-5} and 10^{-4}M GA_3 on growth, photosynthesis, yield and yield attributes of mustard (*Brassica juncea* L.) variety Varuna. They noted that spray of GA_3 proved better than seed soaking, with 10^{-5}M GA_3 spray giving maximum values.

Sumeria (2003), performing a field experiment at Jobner (Rajasthan), studied the effect of three levels of P, viz., 20, 40 and 60 kg P_2O_5 (8.7, 17.5 and 26.2 kg P)/ha on the performance of mustard (*Brassica juncea* L.) variety Varuna. They reported that increasing levels of P enhanced growth parameters, yield attributing characters, seed and fodder yield, N and P content and uptake in seed and straw and oil content.

Mohammad (2004), performing a pot experiment at Aligarh (U.P.), studied the effect of four levels of P, viz. 0, 0.05, 0.10 and 0.15 g P/kg soil, on carbonic anhydrase activity, stomatal conductance, net photosynthesis, leaf N, P and K content and growth and yield characteristics of mustard (*Brassica juncea* L.) variety Varuna. He reported that increasing levels of P application enhanced all parameters linearly.

Siddiqui and Mohammad (2004), conducting a field experiment at Aligarh (U.P.), studied the comparative performance of seven varieties of rapeseed-mustard, viz. IGC-01 and Pusa Gaurav of *Brassica carinata* Braun, Jagannath, Kranti, Rohini and TERI (OE) M21-Swarna of *Brassica juncea* L. and Hyola PAC-401 of *Brassica napus* L., in terms of growth, yield and quality parameters. The recommended dose of 80 kg N + 18 kg P + 30 kg K/ha was applied uniformly to soil. The data revealed the overall superiority of Hyola PAC-401, which gave highest yield of seed and oil. It was followed by TER1 (OE) M21-Swarna, which showed parity with Rohini. In comparison, Kranti performed poorly. It was also found that the oil of Hyola PAC-401 and TERI (OE) M21-Swarna was almost free from erucic acid.

Mohammad *et al.* (2005), conducting a field experiment on mustard (*Brassica juncea* L.) variety Rohini at Aligarh (U.P.), tested the effect of

basal (B) and foliar (F) application of nutrients on yield parameters and fatty acid composition of oil. The treatments included: (i) control, i.e. basal 80 kg N + 30 kg P/ha sprayed with deionized water ($B_{N80P30} + F_w$), (ii) $B_{N60+P30} + F_{N20}$, (iii) $B_{N60P28} + F_{N20P2}$, (iv) $B_{N60P30} + F_{N20S2}$, (v) $B_{N60P28} + F_{N20P2S2}$ and (vi) $B_{N60P28} + F_{N20P2S3.4}$. Basal K was applied uniformly at 30 kg K/ha. The sources of basal N, P and K were commercial grade urea, monocalcium superphosphate and muriate of potash respectively. Leaf-applied nutrients consisted of laboratory grade urea for N (ii-vi), sodium dihydrogen orthophosphate for P (iii, v), sodium sulphate for S (iv, v) and commercial grade monocalcium superphosphate as single source for P and S (vi) The data revealed that, of the six treatments, inclusion of N, P and S in the spray, particularly in the form of commercial grade fertilizers, had a significant ameliorating effect on all yield characteristics as well as erucic acid content of the oil.

2.8 Concluding remarks

The literature covered in the preceding pages clearly establishes that species, and varieties of the same species, differ in their response even under a common set of conditions. Application of GA_3 and of N, P and K influences, to a great extent, the growth and development of mustard. Moreover, their doses and modes of application also affect the performance of the crop. It is also evident that information regarding the effect of the application of GA_3 and Ca on its behaviour was scant at the time of planning of the present project in 2002 and even on its completion no addition seems to have been made. This more than justifies the decision to undertake an in depth study of the response of mustard to GA_3, N, P, K and Ca application.

Materials and Methods

CONTENTS

Chapter 3

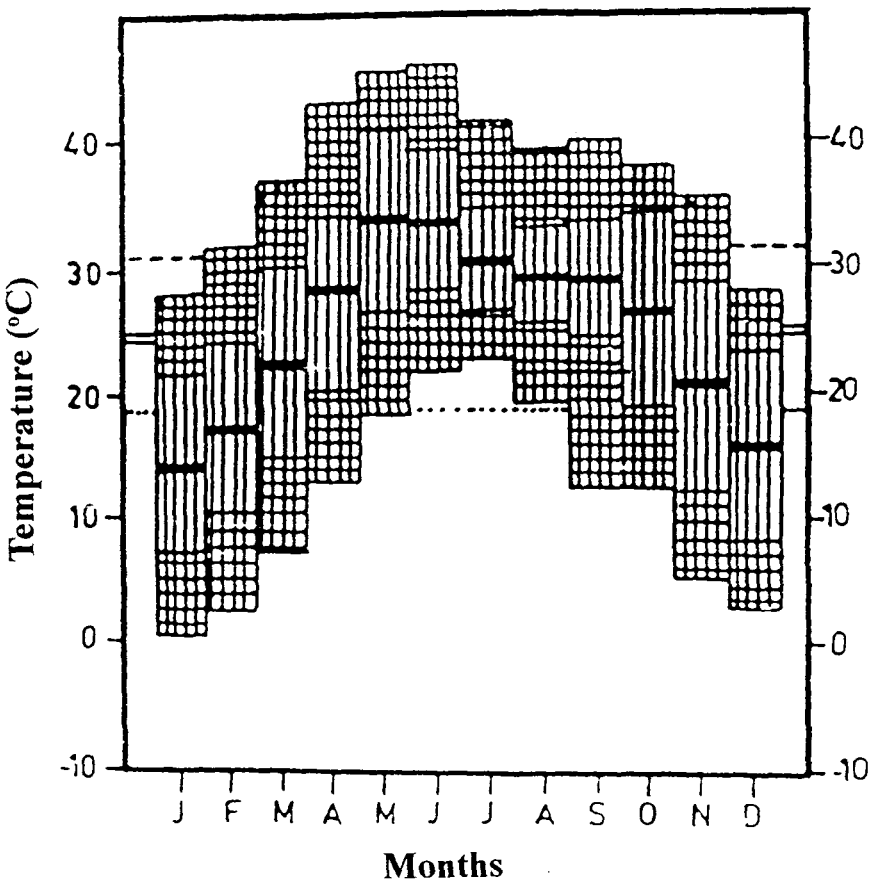
MATERIALS AND METHODS

In the present investigation, four pot experiments were carried out in a net house on mustard (*Brassica juncea* L. Czern. & Coss.) during the 'rabi' (winter) seasons of 2002-2006 at the Department of Botany, Aligarh Muslim University, Aligarh. The details of the materials and methods employed are described below.

3.1 Agro-climatic conditions

Aligarh is one of the seventy districts of Uttar Pradesh (North India) and is situated at 27°52' N latitude, 78°51'E longitude and 187.45 m altitude. It has a semi-arid and sub-tropical climate, with hot dry summers and cold winters. The winter extends from the middle of October to the end of March. The mean temperature of December is 15°C and of January, 13°C and the extreme minimum record for any single day is 2°C and 0.5°C respectively. The summer season stretches from April to the end of June and the mean temperature for May is 34.5°C and for June, 34°C and it sometime reaches up to 45°C for May and 45.5°C for June (Fig. 2).

The average annual rainfall is 847.3 mm. More than 85% of the total rainfall occurs during a short span of four months from June to September. The remaining rain is received during winter (Fig. 3). The winter rains are very useful for 'rabi' crops. But they are sometimes accompanied with high wind velocity and hailstorm. The yearly average of maximum and minimum relative humidity recorded at Aligarh is 68.5 and 44.1% respectively. The monthly average reaches its maximum (81.3%) in August and minimum (31.5%) in May (Fig. 4).



Data based on record from 1901

Extreme Maximum & Minimum

Mean Daily Maximum & Minimum

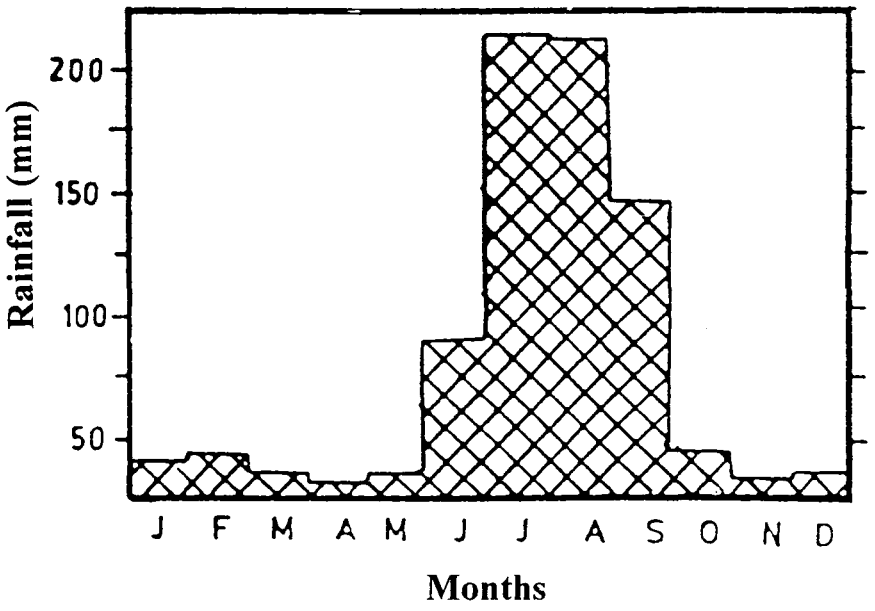
Mean Monthly

Yearly Mean Maximum

Yearly Mean Temperature

Yearly Mean Minimum

Fig. 2 : Monthly temperature variation at Aligarh



Data based on record from 1901

Fig. 3 : Average monthly rainfall at Aligarh

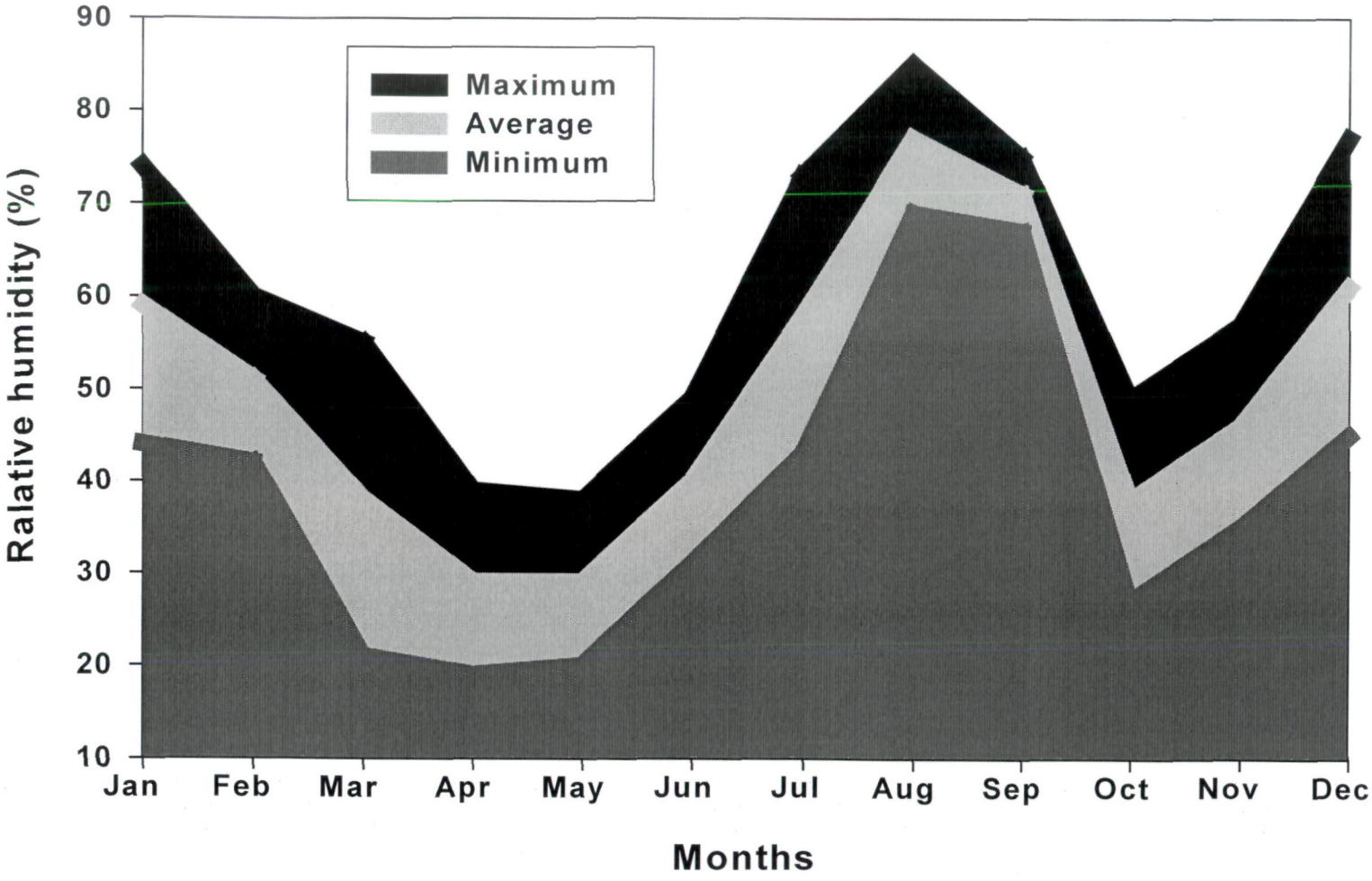


Fig. 4. Monthly relative humidity variation in Aligarh

3.2 Soil characteristics

Three soil samples were collected from a homogenous mixture of soil and well rotten farmyard manure in the ratio of 3:1 before filling the pots. These were mixed thoroughly to get a composite sample and analyzed for various physico-chemical characteristics. Data for each experiment are given in Table 1.

3.3 Filling of pots

Prior to each experiment, earthen pots of equal size (25 cm height and 25 cm diameter) were filled with the homogenous mixture of soil and well rotten farmyard manure at the rate of 5 kg/pot. The required number of pots was placed in the net house according to the design of the experiment. These were irrigated lightly before sowing to provide necessary moisture for germination.

The details of the experiments are given below.

3.4 Experiment 1

This preliminary experiment was performed according to a simple randomized design during 'rabi' season of 2002-2003. The physico-chemical analysis of the soil is given in Table 1.

The aim of this experiment was to select the best performing variety of mustard (*Brassica juncea* L. Czern. & Coss.) out of eighteen newly evolved high yielding varieties on the basis of a screening test. The varieties included Alankar, Amar, Basanti, Black Diamond-21, BS-2 Chapka, Dhanya Laha, Kala Moti, Kesri-100, Krishna-1034, Mahyco Bold, Nath Sona-212, Pusa Agrani, Pusa Bold, Pusa Jaikisan, Rohini, Suraj, T-4001 and Varuna

Table 1. Physico-chemical characteristics of soil before sowing

Soil characteristics	Experiments			
	1 (2002-2003)	2 (2003-2004)	3 (2004-2005)	4 (2005-2006)
Texture	Sandy loam	Sandy loam	Sandy loam	Sandy loam
pH	8.1	8.0	7.8	8.3
EC (dS/m)	0.39	0.44	0.40	0.37
Available N (kg N/ha)	211	203	196	214
Available P (kg P/ha)	18.4	21.5	20.0	25.0
Available K (kg K/ha)	195	212	200	222
Calcium carbonate (%)	0.09	0.11	0.06	0.08

(Table 2). The seeds of these varieties were obtained from the Government authorized seed stores at Aligarh.

The viability of seeds was tested before sowing using the standard method. Healthy seeds of uniform size and weight were selected and surface sterilized with 0.01% mercuric chloride solution (Appendix) followed by repeated washing with double distilled water (DDW). Before sowing, each pot was supplied with the recommended basal dose 40.2 mg N + 13.4 mg P + 13.4 mg K/kg soil (90 kg N + 30 kg P + 30 kg K/ha). Half of the dose of N, along with full dose of P and K, was applied at the time of sowing. The remaining half dose of N was top-dressed after one month of sowing. The sources of N, P and K were urea, sodium dihydrogen orthophosphate and muriate of potash respectively. Ten seeds per pot were sown on 20 October, 2002 and finally four vigorously growing plants per pot were maintained. The pots were irrigated with tap water as and when required and kept free from weeds. For the control of aphid infestation, an insecticide (organophosphorus) was used. There were four replicates for each variety. The crop was harvested on 8 March, 2003. The model of analysis of variance (ANOVA) is given in Table 3.

3.5 Experiment 2

This experiment was conducted according to a factorial randomized design during 'rabi' season of 2003-2004. The physico-chemical analysis of the soil is given in Table 1.

The aim of this experiment was to determine the best combination of pre-sowing seed treatment, i.e. soaking (S) treatment and/or foliar (F) application of GA_3 for Rohini the best performing variety selected on the

Table 2. Summary of Experiment 1 (2002-2003)

Varieties
Alankar
Amar
Basanti
Black Diamond-21
BS-2 Chapka
Dhanya Laha
Kala Moti
Kesri-100
Krishna -1034
Mahyco Bold
Nath Sona-212
Pusa Agrani
Pusa Bold
Pusa Jaikisan
Rohini
Suraj
T-4001
Varuna

NB : A uniform basal dose of 90 kg N + 30 kg P + 30 kg K/ha was applied

Replicates : 4

Varieties : 18

Design : Simple randomized

Table 3. Model of analysis of variance of Experiment 1

Source of variation	DF	SS	MSS	F value
Replicates	3			
Varieties	17			
Error	51			
Total	71			

basis of the data of Experiment 1. The scheme of treatments is given in Table 4 and ANOVA, in Table 5. The seeds were soaked in 0, 10^{-8}, 10^{-6} and 10^{-4}M aqueous solution of GA_3 for 8 h (Appendix) and designated as S0 M GA_3, S10^{-8} M GA_3, S10^{-6} M GA_3, S10^{-4} M GA_3 respectively and the plants thus grown were sprayed with the same concentrations of GA_3 (F0 M GA_3, F10^{-8} M GA_3, F10^{-6} M GA_3, F10^{-4} M GA_3) at 40 days after sowing (DAS), i.e. pre-flowering stage. The duration of soaking and spray stage were selected on the basis of Khan *et al.* (1999) and Mobin (1999). 50 ml solution of each concentration was used for soaking and an equal volume per pot was used for spray treatments. Spray was done with hand sprayer. The control plants were sprayed with DDW. There were four replicates for each treatment. The crop was sown on 16 October, 2003 and harvested on 5 March, 2004.

The other cultural practices, including doses, sources and method of NPK application were the same as in Experiment 1.

3.6 Experiment 3

This experiment was carried out in the 'rabi' season of 2004-2005. The physico-chemical analysis of the soil is given in Table 1. The aim of this factorial randomized experiment was to determine the N and P requirement of the selected variety of mustard (Rohini) grown with the best combination of soaking and spray of GA_3 (S10^{-6} M + F10^{-6}M) emanating from the data of Experiment 2. Five levels of N, viz. 0, 13.4, 26.8, 40.2 and 53.6 mg N/kg soil (0, 30, 60, 90 and 120 kg N/ha designated as N_0, N_{30}, N_{60}, N_{90} and N_{120}) and four levels of P at 0, 6.7, 13.4 and 20.1 mg P/kg soil (0, 15, 30 and 45 kg P/ha designated as P_0, P_{15}, P_{30} and P_{45}) were applied alone

Table 4. Summary of treatments in Experiment 2 (2003-2004)

Foliar (F) treatments ($M\ GA_3$)	Soaking (S) treatments ($M\ GA_3$)			
	0	10^{-8}	10^{-6}	10^{-4}
0				
10^{-8}				
10^{-6}				
10^{-4}				

NB : A uniform basal dose of 90 kg N + 30 kg P + 30 kg K/ha was applied

Replicates : 4

Variety : 1

Design : Factorial randomized

Table 5. Model of analysis of variance of Experiment 2

Source of variation	DF	SS	MSS	F value
Replicates	3			
Soaking treatments	3			
Foliar treatments	3			
Interactions (S x F)	9			
Error	45			
Total	63			

as well as in combination in the presence of a uniform dose of 13.4 mg K/kg soil (30 kg K/ha, i.e. K_{30}). Plants were grown from seeds soaked in 10^{-6}M GA_3 solution for 8 h and sprayed with the same concentration of GA_3 at 40 DAS. Each treatment was replicated four times. The treatments are summarized in Table 6 and ANOVA is given in Table 7. Sowing was done on 25 October, 2004 and harvesting, on 12 March, 2005. The other cultural practices, including sources of nutrients and method of their application, were kept the same as in Experiment 1.

3.7 Experiment 4

This experiment was performed according to a simple randomized design during 'rabi' season of 2005-2006. The physico-chemical analysis of soil is given in Table 1.

The aim of this experiment was to select the best dose of leaf-applied Ca out of 0, 0.45, 0.89 and 1.34 mg Ca/kg soil (0, 1, 2 and 3 kg Ca/ha designated as Ca_0, Ca_1, Ca_2 and Ca_3) for mustard variety Rohini grown with the best dose of basal N, P and K ($N_{90}P_{30}K_{30}$) determined in Experiment 3 and the most potent combination of soaking plus spray of GA_3 ($S10^{-6}M+F10^{-6}$ M) selected on the basis of the data of Experiment 2. The source of Ca was laboratory grade calcium chloride and the plants were sprayed with GA_3 at 40 DAS. There were four replicates for each treatment. The crop was sown on 26 October, 2005 and harvested on 4 March, 2006. The other cultural practices, including sources of N, P and K and method of application of the nutrients and GA_3, were the same as in Experiment 3. The summary of treatments is given in Table 8 and ANOVA in Table 9.

Table 6. Summary of treatments in Experiment 3 (2004-2005)

P treatments (kg P/ha)	N treatments (kg N/ha)				
	0	30	60	90	120
0					
15					
30					
45					

NB : (i) A uniform dose of 30 kg K/ha was applied at the time of sowing

(ii) Seeds were soaked in 10^{-6} M GA_3 solution for 8 h before sowing and the plants grown from these seeds were sprayed with the same concentration of GA_3 at 40 DAS

Replicates : 4

Variety : 1

Design : Factorial randomized

Table 7. Model of analysis of variance of Experiment 3.

Source of variation	DF	SS	MSS	F value
Replicates	3			
N treatments	4			
P treatments	3			
Interactions (N x P)	12			
Error	57			
Total	79			

Table 8. Summary of treatments in Experiment 4 (2005-2006)

Foliar treatments (kg Ca/ha)
0 (control)
1
2
3

NB : (i) A uniform basal dose of 90 kg N + 30 kg P + 30 kg K/ha was applied

(i) Seeds were soaked with 10^{-6} M GA_3 solution for 8 h before sowing and the plants grown with these seeds were sprayed with the same concentration of GA_3 solution containing Ca as per treatment at 40 DAS

Replicates : 4

Variety : 1

Design : Simple randomized

Table 9. Model of analysis of variance of Experiment 4

Source of variation	DF	SS	MSS	F value
Replicates	3			
Treatments	3			
Error	9			
Total	15			

3.8 Sampling techniques

In all the four experiments, random samples, each consisting of four plants, were collected for each treatment at 50 and 60 DAS to study growth and physiological and bio-chemical parameters. The yield characteristics were recorded at harvest (120 DAS). Plants were uprooted a few days before maturity to avoid pod shattering. The harvested crop was subjected to sun drying in the net house to check losses due to birds and rodents. After sun drying, various yield parameters were recorded. Quality of oil was determined after its extraction from seeds.

3.8.1 Growth parameters

The following growth parameters were studied:

1. Shoot length per plant
2. Leaf area (LA) per plant
3. Fresh weight per plant
4. Dry weight per plant

3.8.1.1 Determination of leaf area per plant

It was measured by gravimetric method. The leaf area of three leaves from each plant was calculated by tracing on a graph sheet and dry weight of these leaves was also recorded. The leaf area per plant was calculated by using leaf dry weight per plant and dry weight of those three leaves for which the area was determined using the following formula:

$$LA = \frac{LA_1 \times W_2}{W_1}$$

where,

LA_1 = leaf area of the leaves traced on a graph paper

W_1 = dry weight of leaves for which area was traced on a graph paper.

W_2 = total leaf dry weight per plant

3.8.2 Physiological and bio-chemical parameters

The following physiological and bio-chemical parameters were studied :

1. Net photosynthetic rate
2. Carbonic anhydrase activity
3. Nitrate reductase activity
4. Leaf chlorophyll content
5. Leaf N, P, K and Ca content

3.8.2.1 Determination of net photosynthetic rate

It was measured in fully expanded leaves of plants using a LiCOR-6200, Portable Photosynthesis System (Lincoln, USA), taking care to use leaves of the same age for both control and treated plants. All the measurements were made on cloudless clear days between 11.00 and 13.00 solar time.

3.8.2.2 Estimation of carbonic anhydrase activity

Carbonic anhydrase activity was determined by adopting the method of Dwivedi and Randhawa (1974).

Random samples of leaves from each replicate were taken and cut into small pieces (1 cm^2) at a temperature below 25°C. After mixing them, 200 mg leaf pieces were further cut into smaller pieces (2-3 mm length) keeping them in 10 ml 0.2M cystein (Appendix) in a petridish at 0 to 4°C

and kept for 20 minutes. The solution adhering at their surface was removed with the help of a blotting paper followed by transfer immediately to a test tube, having 4 ml phosphate buffer of pH 6.8 (Appendix). To this, 4 ml 0.2M sodium bicarbonate in 0.02M sodium hydroxide solution and 0.2 ml of 0.002% bromothymol blue indicator (Appendix) were added. After shaking, the tubes were kept at 0-4°C for 20 minutes. Carbon dioxide liberated during catalytic action of the enzyme on sodium bicarbonate was estimated by titrating the reaction mixture against 0.05N hydrochloric acid, using methyl red as an internal indicator (Appendix). The control reaction mixture was also titrated against 0.05N hydrochloric acid. The difference of sample reading and blank reading was noted for further calculation of enzyme activity.

The activity of enzyme was calculated by the following formula :

$$\frac{0.5 \times V \times N}{W} \text{ m mol } (CO_2)\text{/mg (leaf fresh mass)/min}$$

where,

V = difference in volume (ml) of hydrochloric acid used in blank and sample mixtures

N = Normality of hydrochloric acid

W = Weight of leaves (mg) used

T = duration of the catalytic action of the enzyme (min)

Finally, the activity of the enzyme was expressed in terms of mol CO_2/kg (leaf fresh mass)/s.

3.8.2.3 Estimation of nitrate reductase activity

Nitrate reductase activity was estimated in fresh leaf pieces. The enzyme activity was determined according to the method of Jaworski (1971) and is described below.

Fresh leaves (200 mg) were cut into small pieces and transferred to plastic vials. To each vial 2.5 ml phosphate buffer (pH 7.5) and 0.5 ml potassium nitrate solution (0.2M) were added, followed by addition of 2.5 ml 5% isopropanol (Appendix). Finally, 2 drops of chloramphenicol solution were added to avoid bacterial growth in the medium. These vials were incubated for 2 h in dark at 27±2°C.

After 2 h, these vials were taken out from the incubation chamber. From each vial, 0.4 ml incubated mixture was transferred to separate test tubes to which 0.3 ml sulphanilamide (1%) and 0.3 ml 0.02% N-1-nephthyl ethylene diamine hydrochloride (NED-HCl) were added (Appendix). The solution was left for 20 min for maximum colour development. Each tube was diluted to 5 ml with DDW, and the optical density (OD) was read at 540 nm, using a spectrophotometer (Spectronic 20D, Milton Roy, USA).

3.8.2.3.1 Standard curve for nitrate reductase activity

30 mg sodium nitrite was dissolved in and the final volume, made up to 100 ml using DDW. From this solution, 1.0 ml was again diluted to 100 ml. From this diluted solution, ten aliquots, viz. 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6, 1.8 and 2.0 ml were taken in separate test tubes. To each of these, 0.3 ml each of 1% sulphanilamide and 0.02% NED-HCl was added. The solution was left for 20 min for maximum colour development. The solution was diluted to 5ml with DDW and per cent transmittance was read

at 540 nm, using a blank, with the help of the spectrophotometer mentioned above. After converting per cent transmittance into OD, a standard curve was plotted, using the concentrations of sodium nitrite solution versus OD.

The sample reading was compared with the standard curve and NRA was expressed as n mol (NO_2)/g (leaf fresh mass)/h.

3.8.2.4 Estimation of leaf chlorophyll content

Chlorophyll content was estimated following the method of Arnon (1949). The details are described below.

Fresh leaves (1g) were homogenized in a mortar with a pestle in the presence of sufficient quantity of 80% acetone (Appendix). The extract was filtered through Whatman No. 42 filter paper and the filtrate was collected in a 100 ml volumetric flask. The process was repeated thrice and each time filtrate was collected in the same volumetric flask. Finally, the volume was made up to 100 ml with 80% acetone. 5 ml extract from the 100 ml volumetric flask was transferred to a 50 ml volumetric flask and the volume was made up to the mark with 80% acetone. 5 ml sample of chlorophyll extract from the 50 ml volumetric flask was transferred to a cuvette and the absorbancy was read at 645 and 663 nm on a spectrophotometer (Spectronic 20D, Milton Roy, USA).

The following formula was used to calculate the total chlorophyll content in fresh leaves :

$$\text{Total chlorophyll} = [(20.2 \times OD\ 645) + 8.02 \times OD663)] \times \frac{V \times W}{1000}$$

where,

V = volume of the extract in ml

W = weight of the fresh leaves used for the extraction of the pigment in g

3.8.2.5 Estimation of NPK and Ca in leaves

After measuring dry weight of plants, the blades of leaves were finely powdered. The leaf powder was passed through a 70 mesh screen and stored in polythene vials. Details of the estimation procedure are given below.

3.8.2.5.1 Digestion of leaf powder

100 mg oven-dried leaf powder was transferred to a 50 ml Kjeldahl flask to which 2 ml sulphuric acid was added. The content of the flask was heated on a temperature controlled assembly for about 2 h to allow the complete reduction of nitrate present in the plant material by the organic matter itself. As a result, the content of the flask turned black. After cooling the flask for about 15 min, 0.5 ml of 30% hydrogen peroxide (H_2O_2) was added drop by drop and the content of the flask was heated again till the colour turned from black to light yellow. Again, after cooling for 30 minutes an additional 3-4 drops of H_2O_2 (30%) were added, followed by heating for another 15 minutes. The process was repeated till the contents of the flask turned colourless. The peroxide digested material was transferred from the Kjeldahl flask to a 100 ml volumetric flask with three washings with DDW. The volume of the flask was made up to the mark with DDW. This peroxide digested material was used for the estimation of NPK and Ca.

3.8.2.5.2 Nitrogen

N was estimated according to the method of Lindner (1944). A 10 ml aliquot of the digested material was taken in a 50 ml volumetric flask. To

this, 2 ml of 2.5N sodium hydroxide and 1 ml of 10% sodium silicate solution (Appendix) were added to neutralize the excess of acid and to prevent turbidity respectively. The volume of the solution was made up to the mark with DDW. In a 10 ml graduated test tube, 5 ml aliquot of this solution was taken and 0.5 ml Nessler's reagent (Appendix) was added. The content of the test tube was allowed to stand for 5 min for maximum colour development. The solution was transferred to a colorimetric tube and the per cent transmittance was read at 525 nm, using a blank, on a spectrophotometer (Spectronic 20D, Milton Roy, USA). The reading of each sample was compared with a standard calibration curve and nitrogen was expressed in terms of percentage on dry weight.

3.8.2.5.2.1 Standard curve for nitrogen

50 mg ammonium sulphate was dissolved to prepare 1 litre solution using DDW. From this solution 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0 ml were pipetted into ten test tubes separately. The solution in each test tube was diluted to 5 ml with DDW. In each test tube, 0.5 ml Nessler's reagent was added. After 5 min, the per cent transmittance was read at 525 nm, using a blank, on a spectrophotometer (Spectronic 20D, Milton Roy, USA). Standard curve was plotted using different concentration of ammonium sulphate solution versus OD.

3.8.2.5.3 Phosphorus

The method of Fiske and Subba Row (1925) was used to estimate the total phosphorus in the digested material. A 5 ml aliquot was taken in a 10 ml graduated test tube and 1 ml molybdic acid (Appendix) was added carefully, followed by addition of 0.4 ml 1-amino-2-naphthol-4-sulphonic

acid (Appendix). When the colour turned blue, the volume was made up to 10 ml with the addition of DDW. The solution was shaken for 5 min and was then transferred to a colorimetric tube. The per cent transmittance was read at 620 nm, using a blank, on a spectrophotometer (Spectronic 20D, Milton Roy, USA).

3.8.2.5.3.1 Standard curve for phosphorus

351 mg potassium dihydrogen orthophosphate was dissolved in sufficient DDW to which 10 ml sulphuric acid (10N) was added and the final volume was made up to 1 litre with DDW. From this solution, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0 ml aliquots were taken in 10 test tubes separately. The solution in each test tube was diluted to 5 ml with DDW. In each test tube, 1 ml molybdic acid and 0.4 ml 1-amino-2-naphthol-4-sulphonic acid were added. When the colour turned blue, the volume was made up to 10 ml with DDW. After 5 min, the per cent transmittance was read at 620 nm on a spectrophotometer (Spectronic 20D, Milton Roy, USA). A blank was also run simultaneously. The standard curve was plotted using different dilutions of potassium dihydrogen orthophosphate versus OD.

3.8.2.5.4 Potassium

Potassium was estimated with the help of a flame photometer (Fotoflame, AIMIL). After adjusting the filter for potassium in the photometer, 10 ml hydrogen peroxide digested material was run. A blank was also run side by side.

3.8.2.5.4.1 Standard curve for potassium

1.91 g potassium chloride was dissolved to get 100 ml solution using DDW. Of this solution, 1 ml was diluted to 1 litre. The resulting solution was of 10 ppm K. From this 10 ppm K stock solution, 10 ml each of 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10 ppm K was obtained in ten vials separately, adding DDW for proper dilution where required. The solution of each vial was run separately. A blank was also run with each set of determinations. A standard curve was prepared, using different dilutions of potassium chloride solution versus the reading on the scale of the galvanometer.

3.8.2.5.5 Calcium

It was also estimated flamephotometrically. After adjusting the filter for calcium, 10 ml hydrogen peroxide digested material was run. A blank was also run side by side.

3.8.2.5.5.1 Standard curve for calcium

2.5 g calcium carbonate was dissolved in 1000 ml volumetric flask by adding 5 ml hydrochloric acid. After the reaction was over, the final volume was made up to the mark with DDW. Thus, a stock solution containing 1 g Ca/l (1000 ppm Ca) was obtained. From this 1000 ppm Ca stock solution, dilutions containing 10, 20, 30, 40 and 50 ppm Ca were prepared in five vials separately. The solution of each vial was run, adjusting Ca filter in position. A blank was also run with each set of determinations. A calibration curve was plotted in the same way as for potassium.

3.8.3 Yield parameters

The following yield parameters were recorded at harvest :

1. Pod number per plant

2. Seed number per pod

3. 1000-seed weight

4. Seed yield per plant

5. Oil content

6. Oil yield per plant

3.8.3.1 Determination of oil content

After separating them from extraneous material, seeds were crushed to get a fine meal for extracting the oil.

10 g ground seed meal was transferred to a Soxhlet apparatus and a sufficient quantity of petroleum ether was added. The apparatus was kept on a hot water bath, running at 60°C, for about 6 h, for complete extraction of the oil. Petroleum ether from the extract was evaporated after some time. The extracted oil was expressed as a percentage by mass of the seeds and was calculated by the following formula :

$$\text{Percentage of oil} = \frac{\text{Mo} \times 100}{\text{Ms}}$$

where,

Mo = mass of the oil in g

Ms = mass of the seed sample in g

3.8.4 Quality parameters

The oil was analyzed for the following quality parameters :

(1) Acid value

(2) Iodine value

(3) Saponification value

3.8.4.1 Determination of acid value

The acid value of oil is the number of mg of potassium hydroxide required to neutralize free acid in 1 g of oil (mg KOH/g oil). It was determined by the following method (Anonymous, 1970).

2 g oil was taken in a 250 ml conical flask and 50 ml solvent mixture (Appendix) was added to dissolve the oil. Titration was carried out with 0.1N potassium hydroxide solution (Appendix) using phenolphthalein (Appendix) as an indicator. Number of ml 'A' of 0.1N potassium hydroxide required was noted. The acid value was calculated by the following formula:

$$\text{Acid value} = \frac{A \times 0.00561 \times 1000}{W}$$

where,

A = ml of 0.1N KOH used in titration

W = weight of oil (g)

3.8.4.2 Determination of iodine value

The iodine value of an oil is the number of g of iodine absorbed by 100 g oil (g iodine/100 g oil). It was determined by using the iodine monochloride method describe below (Anonymous, 1970).

2 g oil was placed in a dry round bottom flask. To it 10 ml carbon tetrachloride and 20 ml iodine monochloride solution (Appendix) were added. The flask was stoppered and allowed to stand in a dark place for about 30 minutes. Thereafter, 15 ml potassium iodide solution

(Appendix) and 100 ml DDW were poured into the flask with gentle shaking. Titration was carried out with 0.1N sodium thiosulphate solution (Appendix), using starch solution (Appendix) as an indicator. The number of ml 'A' of sodium thiosulphate used was noted. For blank, similar operation was put into practice without the oil and the number of ml 'B' of 0.1N sodium thiosulphate solution used was noted. Iodine value was calculated by the following formula :

$$\text{Iodine value} = \frac{(B-A) \times 0.01269 \times 100}{W}$$

where,

A = number of ml of 0.1N sodium thiosulphate solution used for the sample

B = number of ml of 0.1N sodium thiosulphate solution used for the blank

W = weight of oil (g)

3.8.4.3 Determination of saponification value

The saponification value of oil is the number of mg of potassium hydroxide required to neutralize the fatty acids resulting from complete hydrolysis of 1 g of oil (mg KOH/g oil).

2 g oil was taken in a 250 ml conical flask to which 25 ml 0.5N potassium hydroxide solution (Appendix) was added. The flask was attached with a reflux condenser and heated on a water bath for about 1 h with frequent rotation of the contents of the flasks. After cooling, 1 ml phenolphthalein solution was added. The excess of alkali was titrated with 0.5N hydrochloride solution (Appendix) and the number of ml 'A' was

noted. For blank, the operation was repeated in the same manner omitting the oil, and the number of ml 'B' required was noted. Saponification value was calculated by the following formula (Anonymous, 1970):

$$\text{Saponification value} = \frac{(B-A) \times 0.02805 \times 1000}{W}$$

where,

A = number of ml of 0.5N HCl used in the sample

B = number of ml of 0.5 N HCl used in the blank

W = weight of oil (g)

3.8.5 Statistical analysis

All experimental data were statistically analyzed by adopting the analysis of variance technique, according to Gomez and Gomez (1984). In applying the F test, the error due to replicates was also determined. When 'F' value was found to be significant at 5% level of probability, critical difference (CD) was calculated.

Experimental Results

CONTENTS

Chapter 4

EXPERIMENTAL RESULTS

The results of the four pot experiments on mustard (*Brassica juncea* L. Czern. and Coss.) are reported in this chapter. The important results are described experiment-wise below and are summarized in Tables 10-56.

4.1 Experiment 1

In this simple randomized experiment, the performance of eighteen newly evolved high yielding varieties of mustard, namely Alankar, Amar, Basanti, Black Diamond-21, BS-2 Chapka, Dhanya Laha, Kala Moti, Kesri-100, Krishna-1034, Mahyco Bold, Nath Sona-212, Pusa Agrani, Pusa Bold, Pusa Jaikisan, Rohini, Suraj, T-4001 and Varuna was studied in terms of growth parameters, physiological and bio-chemical response and, yield and quality characteristics (Tables 10-17). The data are described briefly below.

4.1.1 Growth parameters

Varieties were found to differ in respect of all growth parameters studied at 50 and 60 DAS (Tables 10-11). The individual parameters are described below.

4.1.1.1 Shoot length per plant

Varuna at 50 DAS and Pusa Jaikisan at 60 DAS attained maximum height among the varieties. However, their vertical growth was at par with that of Pusa Bold and Rohini at both stages. Rohini gave 30.3% and 27.2% higher value at 50 and 60 DAS respectively than Suraj that produced the shortest plants (Table 10).

Table 10. Evaluation of mustard varieties for shoot length per plant and leaf area per plant at two stages of growth (mean of four replicates)

Varieties	Shoot length per plant (cm)		Leaf area per plant (cm^2)	
	50 DAS	60 DAS	50 DAS	60 DAS
Alankar	25.8	27.8	335.2	352.3
Amar	24.4	28.3	325.5	343.5
Basanti	24.6	28.0	328.0	341.0
Black Diamond-21	25.1	28.6	324.1	347.6
BS-2 Chapka	24.4	27.5	332.7	338.1
Dhanya Laha	24.0	27.3	322.8	336.2
Kala Moti	25.4	27.1	330.9	351.0
Kesri-100	23.7	28.5	321.2	333.1
Krishna-1034	26.4	27.5	342.3	359.5
Mahyco Bold	26.6	28.9	341.0	356.7
Nath Sona-212	26.4	28.8	340.0	352.8
Pusa Agrani	26.1	27.2	343.6	359.3
Pusa Bold	29.7	32.0	384.7	405.5
Pusa Jaikisan	30.4	33.4	385.2	416.6
Rohini	29.7	33.2	390.5	420.0
Suraj	22.8	26.1	316.6	330.2
T-4001	23.6	26.8	319.8	332.5
Varuna	30.5	32.5	375.0	409.6
CD at 5%	2.62	2.50	29.36	40.59

NB : A uniform basal dose of $N_{90}P_{30}K_{30}$ was applied

4.1.1.2 Leaf area per plant

Rohini, being at par with Pusa Bold, Pusa Jaikisan and Varuna, developed maximum leaf area at both 50 and 60 DAS. Rohini exhibited 23.3% and 27.2% more leaf area at 50 and 60 DAS respectively than Suraj which gave the least value at both stages (Table 10).

4.1.1.3 Fresh weight per plant

Rohini, equalled by Pusa Jaikisan and Varuna, produced maximum fresh matter at both stages. It gave 24.6 and 29.1% higher fresh weight at 50 and 60 DAS respectively than Suraj which gave minimum value at both stages (Table 11).

4.1.1.4 Dry weight per plant

Rohini surpassed the other varieties in dry matter production at both stages. However, it was equalled by Varuna, Pusa Jaikisan and Pusa Bold at 50 DAS and by Pusa Jaikisan and Varuna at 60 DAS. Variety Rohini produced 17.6 and 20.7% more dry matter at 50 and 60 DAS respectively than Suraj which gave the lowest value at both stages (Table 11).

4.1.2 Physiological and bio-chemical parameters

Varietal differences were found to be significant in respect of physiological and bio-chemical parameters studied at 50 and 60 DAS (Tables 12-14). The data of individual parameters are briefly described below.

4.1.2.1 Net photosynthetic rate

Rohini exhibited maximum net photosynthetic rate at both stages. However, it showed parity with Varuna and Pusa Jaikisan at 50 DAS and

Table 11. Evaluation of mustard varieties for fresh weight per plant and dry weight per plant at two stages of growth (mean of four replicates)

Varieties	Fresh weight per plant (g)		Dry weight per plant (g)	
	50 DAS	60 DAS	50 DAS	60 DAS
Alankar	5.45	5.71	2.05	2.11
Amar	5.31	5.49	1.98	2.07
Basanti	5.33	5.53	1.99	2.10
Black Diamond-21	5.39	5.63	2.00	2.08
BS-2 Chapka	5.31	5.48	1.97	2.06
Dhanya Laha	5.24	5.40	1.96	2.05
Kala Moti	5.41	5.66	2.03	2.10
Kesri-100	5.19	5.38	1.95	2.05
Krishna-1034	5.64	5.87	2.06	2.16
Mahyco Bold	5.55	5.80	2.05	2.14
Nath Sona-212	5.47	5.78	2.04	2.13
Pusa Agrani	5.60	5.82	2.06	2.15
Pusa Bold	5.67	5.89	2.19	2.23
Pusa Jaikisan	6.15	6.37	2.24	2.41
Rohini	6.23	6.74	2.27	2.45
Suraj	5.00	5.22	1.93	2.03
T-4001	5.15	5.38	1.94	2.03
Varuna	6.11	6.50	2.25	2.40
CD at 5%	0.35	0.40	0.12	0.15

NB : A uniform basal dose of $N_{90}P_{30}K_{30}$ was applied

with Pusa Jaikisan, Varuna and Pusa Bold at 60 DAS. Rohini gave 18.5 and 25.9% higher value at 50 and 60 DAS respectively than Suraj which gave the minimum value at 60 DAS (Table 12).

4.1.2.2 Carbonic anhydrase activity

Rohini showed maximum activity of this enzyme at both stages. However, it was equalled by Pusa Jaikisan, Varuna and Pusa Bold at 50 DAS and by Pusa Jaikisan at 60 DAS. Rohini gave 20.1 and 31.0% higher value at 50 and 60 DAS respectively than Suraj which exhibited minimum carbonic anhydrase activity at 60 DAS (Table 12).

4.1.2.3 Nitrate reductase activity

Rohini, Pusa Jaikisan, Varuna and Pusa Bold, being at par, gave higher values than the other varieties at both stages. Rohini showed 25.1 and 21.2% higher nitrate reductase activity at 50 and 60 DAS respectively than Suraj which gave the lowest value at both stages (Table 13).

4.1.2.4 Leaf chlorophyll content

Rohini had maximum value for chlorophyll content at both stages. However, it was at par with Pusa Bold at 50 DAS and was followed by Pusa Jaikisan, Varuna and Pusa Bold at 60 DAS. Rohini exhibited 20.9 and 31.7% higher leaf chlorophyll content at 50 and 60 DAS respectively than Suraj which had the lowest value at both stages (Table 13).

4.1.2.5 Leaf N content

Varuna, Rohini and Pusa Jaikisan, being at par, showed higher values for this parameter than the others at both stages. However, these varieties also showed parity with Pusa Bold at 60 DAS. Rohini exhibited

Table 12. Evaluation of mustard varieties for net photosynthetic rate and carbonic anhydrase activity at two stages of growth (mean of four replicates)

Varieties	Net photosynthetic rate [μ mol (CO_2)/m^2/s]		Carbonic anhydrase activity [mol (CO_2)/kg (f.m.)/s]	
	50 DAS	60 DAS	50 DAS	60 DAS
Alankar	12.45	13.70	1.49	1.62
Amar	12.66	13.14	1.45	1.55
Basanti	12.74	13.32	1.46	1.54
Black Diamond-21	12.83	13.42	1.48	1.60
BS-2 Chapka	12.56	12.94	1.43	1.56
Dhanya Laha	12.47	12.84	1.42	1.53
Kala Moti	12.88	13.54	1.50	1.62
Kesri-100	12.42	12.71	1.40	1.51
Krishna-1034	13.14	14.21	1.53	1.69
Mahyco Bold	13.10	13.95	1.50	1.66
Nath Sona-212	13.01	13.85	1.51	1.65
Pusa Agrani	13.20	14.08	1.52	1.67
Pusa Bold	13.25	15.28	1.62	1.79
Pusa Jaikisan	14.41	15.80	1.67	1.88
Rohini	14.62	15.84	1.67	1.90
Suraj	12.34	12.58	1.39	1.45
T-4001	12.02	12.94	1.36	1.50
Varuna	14.53	15.37	1.63	1.78
CD at 5%	0.95	0.76	0.06	0.08

NB : A uniform basal dose of $N_{90}P_{30}K_{30}$ was applied

Table 13. Evaluation of mustard varieties for nitrate reductase activity and leaf chlorophyll content at two stages of growth (mean of four replicates)

Varieties	Nitrate reductase activity [n mol (NO_2)/g(f.m.)/h]		Leaf chlorophyll content (g/kg)	
	50 DAS	60 DAS	50 DAS	60 DAS
Alankar	274.08	292.80	1.108	1.161
Amar	280.86	299.80	1.085	1.128
Basanti	276.34	294.86	1.092	1.147
Black Diamond-21	280.95	291.74	1.095	1.143
BS-2 Chapka	272.82	297.92	1.082	1.126
Dhanya Laha	269.56	290.68	1.080	1.108
Kala Moti	277.60	299.98	1.095	1.155
Kesri-100	273.45	288.62	1.073	1.093
Krishna-1034	287.64	305.10	1.138	1.192
Mahyco Bold	284.12	301.98	1.123	1.175
Nath Sona-212	283.65	300.92	1.113	1.170
Pusa Agrani	285.38	307.04	1.131	1.182
Pusa Bold	312.65	329.45	1.260	1.289
Pusa Jaikisan	326.75	341.19	1.160	1.335
Rohini	326.00	342.19	1.268	1.408
Suraj	260.50	282.33	1.049	1.069
T-4001	268.30	287.56	1.071	1.083
Varuna	314.98	332.22	1.145	1.297
CD at 5%	14.70	20.53	0.09	0.07

NB : A uniform basal dose of $N_{90}P_{30}K_{30}$ was applied

20.6 and 22.8% higher leaf N content at 50 and 60 DAS respectively than Suraj which gave the lowest value at both stages (Table 14).

4.1.2.6 Leaf P content

P content was maximum in Pusa Jaikisan at both stages. However, it was equalled by Rohini, Pusa Bold and Varuna at 50 DAS and was followed by Varuna, Rohini, Pusa Bold, Krishna-1034, Mahyco Bold, Pusa Agrani, Nath Sona-212, Basanti, Kala Moti, Black Dimond-21, Alankar and Amar at 60 DAS. Pusa Jaikisan gave 14.0 and 15.8% higher value at 50 and 60 DAS respectively than Suraj which gave the minimum value at 60 DAS. Rohini gave 12.8 and 7.7% higher value at 50 and 60 DAS respectively than Suraj (Table 14).

4.1.2.7 Leaf K content

Varieties Varuna and Rohini, being at par, gave the highest value for leaf K content at both growth stages. However, they also showed parity with Pusa Jaikisan and Pusa Bold at 60 DAS. Rohini had 14.5 and 18.9% more leaf K content at 50 and 60 DAS respectively than Alankar which gave the least value. Moreover, Rohini gave 10.1 and 10.1% higher value at 50 and 60 DAS respectively than Suraj (Table 14).

4.1.3 Yield parameters

Varietal differences were found to be significant for all yield parameters studied at harvest. The data are presented in Tables 15-16 and are described briefly below.

Table 14. Evaluation of mustard varieties for leaf nitrogen, phosphorus and potassium content at two stages of growth (mean of four replicates)

Varieties	N content (%)		P content (%)		K content (%)	
	50 DAS	60 DAS	50 DAS	60 DAS	50 DAS	60 DAS
Alankar	2.40	2.34	0.268	0.254	3.44	3.12
Amar	2.42	2.27	0.265	0.253	3.54	3.25
Basanti	2.37	2.29	0.263	0.257	3.53	3.31
Black Diamond-21	2.36	2.30	0.265	0.255	3.51	3.32
BS-2 Chapka	2.34	2.24	0.262	0.251	3.51	3.22
Dhanya Laha	2.33	2.21	0.261	0.251	3.50	3.20
Kala Moti	2.40	2.33	0.267	0.257	3.57	3.36
Kesri-100	2.31	2.19	0.275	0.249	3.47	3.49
Krishna-1034	2.45	2.39	0.259	0.262	3.66	3.15
Mahyco Bold	2.47	2.36	0.272	0.260	3.65	3.43
Nath Sona-212	2.46	2.34	0.271	0.258	3.46	3.41
Pusa Agrani	2.44	2.37	0.274	0.260	3.62	3.45
Pusa Bold	2.56	2.53	0.287	0.263	3.79	3.74
Pusa Jaikisan	2.73	2.54	0.293	0.286	3.81	3.74
Rohini	2.75	2.59	0.290	0.266	3.94	3.71
Suraj	2.28	2.11	0.257	0.247	3.58	3.37
T-4001	2.30	2.16	0.254	0.248	3.61	3.14
Varuna	2.75	2.60	0.280	0.268	3.95	3.72
CD at 5%	0.16	0.13	0.013	0.015	0.12	0.11

NB : A uniform basal dose of $N_{90}P_{30}K_{30}$ was applied

4.1.3.1 Pod number per plant

Rohini, equalled by Varuna, Pusa Jaikisan and Pusa Bold, exhibited maximum value. It produced 24.5% more pods than Suraj which gave the lowest value (Table 15).

4.1.3.2 Seed number per pod

Maximum number of seeds per pod was recorded in Rohini. However, it showed parity with Pusa Jaikisan. Rohini gave 16.3% higher value than the lowest value giving variety T-4001 and 6.4% higher value than Suraj (Table 15).

4.1.3.3 1000-seed weight

Varuna produced the heaviest seeds. However, the value was at par with that of Rohini and Pusa Jaikisan. Rohini gave 15.7% higher seed weight than Suraj which gave the lowest value (Table 15).

4.1.3.4 Seed yield per plant

Rohini gave the maximum seed yield but it was at par with Pusa Jaikisan, Varuna and Pusa Bold. Rohini gave 19.5% higher seed yield than Suraj which gave the minimum value (Table 16).

4.1.3.5 Oil content

Varuna exhibited the highest percentage of oil in seeds. However, it was at par with Pusa Jaikisan which also showed parity with Rohini. Varuna had 7.7% higher oil content than the least value giving variety Suraj. Moreover, Rohini gave 6.3% higher value than Suraj (Table 16).

Table 15. Evaluation of mustard varieties for pod number per plant, seed number per pod and 1000-seed weight at harvest (mean of four replicates)

Varieties	Pod number per plant	Seed number per pod	1000-seed weight(g)
Alankar	97.00	11.50	3.99
Amar	94.50	11.00	3.95
Basanti	95.75	11.75	3.93
Black Diamond-21	96.50	11.50	3.96
BS-2 Chapka	92.00	11.50	3.91
Dhanya Laha	92.75	11.00	3.84
Kala Moti	96.75	11.75	3.97
Kesri-100	91.50	10.75	3.88
Krishna-1034	99.00	11.00	4.04
Mahyco Bold	98.75	11.75	4.09
Nath Sona-212	97.00	10.75	4.00
Pusa Agrani	101.00	11.75	4.06
Pusa Bold	108.75	12.00	4.13
Pusa Jaikisan	109.50	12.50	4.35
Rohini	110.50	12.50	4.36
Suraj	88.75	11.75	3.77
T-4001	90.50	10.75	3.82
Varuna	109.75	12.00	4.38
CD at 5%	7.43	0.23	0.20

NB : A uniform basal dose of $N_{90}P_{30}K_{30}$ was applied

Table 16. Evaluation of mustard varieties for seed yield per plant seed, oil content and oil yield per plant at harvest (mean of four replicates)

Varieties	Seed yield per plant (g)	Oil content (%)	Oil yield per plant (g)
Alankar	6.28	35.45	2.22
Amar	6.25	34.93	2.18
Basanti	6.20	34.92	2.18
Black Diamond-21	6.18	35.07	2.19
BS-2 Chapka	6.17	34.82	2.15
Dhanya Laha	6.08	34.71	2.11
Kala Moti	6.28	35.26	2.23
Kesri-100	6.04	34.59	2.10
Krishna-1034	6.39	35.64	2.29
Mahyco Bold	6.37	35.58	2.26
Nath Sona-212	6.30	35.53	2.24
Pusa Agrani	6.40	35.72	2.29
Pusa Bold	6.92	36.20	2.51
Pusa Jaikisan	7.15	36.62	2.65
Rohini	7.18	36.38	2.68
Suraj	6.01	34.21	2.03
T-4001	6.04	34.43	2.08
Varuna	7.01	36.85	2.55
CD at 5%	0.42	0.25	0.14

NB : A uniform basal dose of $N_{90}P_{30}K_{30}$ was applied

4.1.3.6 Oil yield per plant

Rohini registered the highest value for this parameter. However, it was at par with Pusa Jaikisan and Varuna. Rohini gave 32.02% higher oil yield than Suraj which gave the lowest value (Table 16).

4.1.4 Quality parameters

Varieties varied with regard to iodine and saponification values. However, varietal differences were non-significant as far as acid value was concerned (Table 17). The data are described briefly below.

4.1.4.1 Acid value

Varieties did not differ in respect of this parameter as mentioned above (Table 17).

4.1.4.2 Iodine value

Suraj gave the maximum value. However, it was at par with T-4001, Pusa Jaikisan and Pusa Bold. Suraj gave 3.6% higher iodine value than Rohini which gave the minimum value (Table 17).

4.1.4.3 Saponification value

Rohini gave highest saponification value. However, it showed parity with Varuna, Pusa Jaikisan and Pusa Bold. Rohini exhibited 4.2% higher value than Nath Sona-212 which gave the minimum value (Table 17).

4.2 Experiment 2

It may be recalled that this factorial randomized design experiment was carried out to determine the best pre-sowing seed and/or foliar treatment with GA_3 both in the 0, 10^{-8}, 10^{-6} and 10^{-4} M GA_3 range on the basis of the performance of mustard (*Brassica juncea* L. Czern. & Coss.) variety Rohini

Table 17. Evaluation of mustard varieties for acid, iodine and saponification value at harvest (mean of four replicates)

Varieties	Acid value	Iodine value	Saponification value
Alankar	3.65	100.48	173.90
Amar	3.52	99.46	176.22
Basanti	3.44	99.76	174.05
Black Diamond-21	3.57	100.04	174.50
BS-2 Chapka	3.41	101.51	173.70
Dhanya Laha	3.34	99.15	172.34
Kala Moti	3.76	100.26	175.92
Kesri-100	3.32	98.94	172.08
Krishna-1034	3.61	99.26	176.79
Mahyco Bold	3.71	101.04	177.28
Nath Sona-212	3.68	100.84	171.99
Pusa Agrani	3.72	101.29	177.08
Pusa Bold	3.79	101.97	178.81
Pusa Jaikisan	3.04	102.07	178.90
Rohini	4.17	98.68	179.28
Suraj	3.22	102.23	176.44
T-4001	3.28	102.14	172.03
Varuna	4.10	98.85	179.05
CD at 5%	N.S.	0.35	1.32

NB : A uniform basal dose of $N_{90}P_{30}K_{30}$ was applied

that proved best in the varietal trial. The parameters studied were also kept the same as in that Experiment. The results (Tables 18-32) are summarized below.

4.2.1 Growth parameters

The effect of pre-sowing seed treatment and foliar application of GA_3 alone, as well as in combination, was significant on all growth parameters studied at 50 and 60 DAS (Tables 18-21).

4.2.1.1 Shoot length per plant

At both stages, pre-sowing seed treatment $S10^{-6}M$ GA_3 proved best. However, the effect of this treatment was at par with that of $S10^{-4}M$ GA_3. Soaking treatment $S10^{-6}M$ GA_3 increased the shoot length by 14.0 and 8.6% at 50 and 60 DAS respectively over the water-soaked treatment at both stages.

Among foliar treatments, $F10^{-6}M$ GA_3 proved best but its effect was at par with that of $F10^{-4}M$ GA_3 at both stages. Spray treatment $F10^{-6}M$ GA_3 gave 21.8 and 18.1% higher shoot length at 50 and 60 DAS respectively than the water-sprayed treatment.

Interaction $S10^{-4}M$ GA_3 x $F10^{-4}M$ GA_3 gave maximum value at both stages. However, its effect was at par with that of $S10^{-6}M$ GA_3 x $F10^{-4}$ M GA_3, $S10^{-4}M$ GA_3 x $F10^{-6}M$ GA_3 and $S10^{-6}M$ GA_3 x $F10^{-6}M$ GA_3 at both stages. Interaction $S10^{-6}M$ GA_3 x $F10^{-6}$ M GA_3 gave 37.0 and 30.9% higher shoot length at 50 and 60 DAS respectively than S 0 M GA_3 x F 0 M GA_3 (control) that produced the shortest plants at both stages (Table 18).

Table 18. Effect of pre-sowing seed treatment and foliar application of GA_3 on shoot length per plant (cm) of mustard variety Rohini at two stages of growth (mean of four replicates)

Foliar (F) treatments (M GA_3)	**Soaking (S) treatments (M GA_3)**				**Mean**
	0	10^{-8}	10^{-6}	10^{-4}	
			50 DAS		
0	30.8	32.6	33.8	34.0	32.80
10^{-8}	33.3	35.4	37.0	37.3	35.75
10^{-6}	36.0	39.3	42.2	42.3	39.95
10^{-4}	36.3	39.5	42.5	42.6	40.23
Mean	34.10	36.70	38.88	39.05	
CD at 5%	S=1.19		F = 1.19	SxF = 2.38	
			60 DAS		
0	33.7	35.8	36.4	37.0	35.73
10^{-8}	36.7	37.1	38.5	40.3	38.15
10^{-6}	39.9	40.4	44.1	44.3	42.18
10^{-4}	40.3	40.6	44.5	44.6	42.50
Mean	37.65	38.48	40.88	41.55	
CD at 5%	S=1.48		F = 1.48	SxF = 2.96	

NB : A uniform basal dose of $N_{90}P_{30}K_{30}$ was applied

4.2.1.2 Leaf area per plant

At both stages, soaking treatment $S10^{-4}M$ GA_3 gave maximum leaf area. However, its value was at par with that of $S10^{-6}M$ GA_3 and $S10^{-8}M$ GA_3. Treatment $S10^{-6}M$ GA_3 gave 6.6 and 6.1% more leaf area at 50 and 60 DAS respectively than the water-soaked treatment.

Among foliar treatments, $F10^{-6}M$ GA_3 proved best at both stages. However, it showed parity with $F10^{-4}M$ GA_3 at each stage. Spray treatment $F10^{-6}M$ GA_3 gave 9.9 and 8.0% higher value at 50 and 60 DAS respectively than the water-sprayed treatment which exhibited minimum leaf area at both stages.

At each stage, interaction $S10^{-4}M$ GA_3 x $F10^{-6}$ M GA_3 exhibited maximum leaf area. However, its effect was at par with that of $S10^{-4}M$ GA_3 x $F10^{-4}$ M GA_3, $S10^{-6}M$ GA_3 x $F10^{-4}M$ GA_3, $S10^{-6}M$ GA_3 x $F10^{-6}M$ GA_3, $S10^{-8}$ M GA_3 x $F10^{-4}M$ GA_3, $S10^{-4}M$ GA_3 x $F10^{-8}M$ GA_3, S 0 M GA_3 x $F10^{-4}M$ GA_3, $S10^{-8}M$ GA_3 x $F10^{-6}$ MGA_3, S 0M GA_3 x $F10^{-6}M$ GA_3, $S10^{-6}M$ GA_3 x $F10^{-8}M$ GA_3. Interaction $S10^{-6}M$ GA_3 x F 0 M GA_3 also showed parity with $S10^{-4}$ M GA_3 x $F10^{-6}$ M GA_3 that gave the maximum leaf area at 60 DAS. Interaction $S10^{-6}M$ GA_3 x $F10^{-6}$ M GA_3 gave 16.9 and 14.5% more leaf area at 50 and 60 DAS respectively than the control (Table 19).

4.2.1.3 Fresh weight per plant

Of the pre-sowing seed treatments, $S10^{-6}M$ GA_3 proved best at each stage. However, the effect of this treatment was at par with that of $S10^{-4}M$ GA_3 at both stages. Soaking treatment $S10^{-6}M$ GA_3 exhibited 6.2 and 7.1% higher value at 50 and 60 DAS respectively than the water-soaked treatment.

Table 19. Effect of pre-sowing seed treatment and foliar application of GA_3 on leaf area per plant (cm^2) of mustard variety Rohini at two stages of growth (mean of four replicates)

Foliar (F) treatments (M GA_3)	**Soaking (S) treatments (M GA_3)**				**Mean**
	0	10^{-8}	10^{-6}	10^{-4}	
			50 DAS		
0	396.5	402.6	410.4	413.9	405.85
10^{-8}	407.4	412.6	430.1	425.0	418.78
10^{-6}	426.2	427.1	463.3	467.0	445.90
10^{-4}	420.3	434.0	456.1	459.5	442.48
Mean	412.60	419.08	439.98	441.35	
CD at 5%	S=24.28		F = 24.28	SxF = 48.57	
			60 DAS		
0	423.2	427.5	443.5	440.1	433.58
10^{-8}	433.0	438.9	446.3	452.1	442.58
10^{-6}	446.5	451.0	484.4	490.9	468.20
10^{-4}	451.9	455.3	487.1	487.2	470.38
Mean	438.65	443.18	465.33	467.58	
CD at 5%	S=25.19		F = 25.19	SxF = 50.38	

NB : A uniform basal dose of $N_{90}P_{30}K_{30}$ was applied

At both stages, foliar treatment $F10^{-6}M$ GA_3 proved best. However, its effect was at par with that of $F10^{-4}M$ GA_3. Spray treatment $F10^{-6}M$ GA_3 gave 9.3 and 10.2% higher fresh weight at 50 and 60 DAS respectively than the water-sprayed treatment.

At 50 DAS, interaction $S10^{-6}M$ GA_3 x $F10^{-4}M$ GA_3 gave the maximum value. However, its effect was at par with that of $S10^{-4}M$ GA_3 x $F10^{-4}M$ GA_3, $S10^{-6}M$ GA_3 x $F10^{-6}M$ GA_3, $S10^{-4}M$ GA_3 x $F10^{-6}M$ GA_3 and $S10^{-8}M$ GA_3 x $F10^{-4}M$ GA_3. These interactions also showed parity among themselves at 60 DAS. Interaction, $S10^{-6}M$ GA_3 x $F10^{-6}M$ GA_3 gave 17.3 and 18.4% higher fresh weight than the control (Table 20).

4.2.1.4 Dry weight per plant

At both stages, pre-sowing seed treatment $S10^{-6}M$ GA_3 proved best. However, the effect of this treatment was at par with that of $S10^{-4}M$ GA_3 at either stage. Soaking treatment $S10^{-4}M$ GA_3 produced 6.4 and 6.1% more dry matter at 50 and 60 DAS respectively than the water-soaked treatment.

At each stage, foliar treatment $F10^{-6}M$ GA_3 proved best. However, its effect was equal to that of $F10^{-4}M$ GA_3. Spray treatment $F10^{-6}M$ GA_3 gave 9.1 and 7.8% higher dry weight at 50 and 60 DAS respectively than the water-sprayed treatment.

At both stages, interaction $S10^{-4}M$ GA_3 x $F10^{-4}M$ GA_3 gave maximum dry weight. However, the effect of this treatment was at par with that of $S10^{-6}M$ GA_3 x $F10^{-4}M$ GA_3, $S10^{-4}M$ GA_3 x $F10^{-6}M$ GA_3 and $S10^{-6}M$ GA_3 x $F10^{-6}M$ GA_3. Interaction $S10^{-6}M$ GA_3 x $F10^{-6}M$ GA_3 gave 16.6 and 15.2% higher value than the control (Table 21).

Table 20. Effect of pre-sowing seed treatment and foliar application of GA_3 on fresh weight per plant (g) of mustard variety Rohini at two stages of growth (mean of four replicates)

Foliar (F) treatments (M GA_3)	**Soaking (S) treatments (M GA_3)**				**Mean**
	0	10^{-8}	10^{-6}	10^{-4}	
			50 DAS		
0	6.26	6.40	6.66	6.57	6.47
10^{-8}	6.54	6.64	6.68	6.81	6.67
10^{-6}	6.78	6.88	7.34	7.27	7.07
10^{-4}	6.91	7.00	7.44	7.38	7.18
Mean	6.62	6.73	7.03	7.01	
CD at 5%	S=0.24		F = 0.24	SxF = 0.48	
			60 DAS		
0	6.63	6.86	6.99	7.08	6.89
10^{-8}	6.98	7.19	7.35	7.39	7.23
10^{-6}	7.22	7.40	7.85	7.90	7.59
10^{-4}	7.29	7.48	7.94	7.99	7.68
Mean	7.03	7.23	7.53	7.59	
CD at 5%	S=0.26		F = 0.26	SxF = 0.52	

NB : A uniform basal dose of $N_{90}P_{30}K_{30}$ was applied

Table 21. Effect of pre-sowing seed treatment and foliar application of GA_3 on dry weight per plant (g) of mustard variety Rohini at two stages of growth (mean of four replicates)

Foliar (F) treatments (M GA_3)	**Soaking (S) treatments (M GA_3)**				**Mean**
	0	10^{-8}	10^{-6}	10^{-4}	
			50 DAS		
0	2.23	2.27	2.33	2.35	2.30
10^{-8}	2.31	2.32	2.38	2.41	2.36
10^{-6}	2.39	2.43	2.60	2.63	2.51
10^{-4}	2.41	2.45	2.64	2.65	2.54
Mean	2.34	2.37	2.49	2.51	
CD at 5%	S=0.08		F = 0.08	SxF = 0.16	
			60 DAS		
0	2.37	2.42	2.45	2.47	2.43
10^{-8}	2.45	2.48	2.50	2.52	2.49
10^{-6}	2.49	2.53	2.73	2.73	2.62
10^{-4}	2.51	2.54	2.74	2.75	2.64
Mean	2.46	2.49	2.61	2.62	
CD at 5%	S=0.09		F = 0.09	SxF = 0.18	

NB : A uniform basal dose of $N_{90}P_{30}K_{30}$ was applied

4.2.2 Physiological and bio-chemical parameters

The effect of pre-sowing seed treatment and foliar treatment of GA_3, alone as well as in combination, was significant on all parameters, except NPK content at both stages as also interaction effect on carbonic anhydrase and nitrate reductase activities and net photosynthetic rate at 50 and 60 DAS (Tables 22-28).

4.2.2.1 Net photosynthetic rate

At both stages, pre-sowing seed treatment $S10^{-6}M$ GA_3 proved best. However, the effect of this treatment was at par with that of $S10^{-4}M$ GA_3. Soaking treatment $S10^{-6}M$ GA_3 increased the net photosynthetic rate by 9.2 and 8.8% at 50 and 60 DAS respectively than the water-soaked treatment.

Among foliar treatments, $F10^{-6}M$ GA_3 proved best but its effect was equal to that of $F10^{-4}M$ GA_3 at both stages. Spray treatment $F10^{-6}M$ GA_3 gave 11.5 and 13.0% higher net photosynthetic rate at 50 and 60 DAS respectively than the water-sprayed treatment.

Interaction effect on this parameter was found to be non-significant at 50 DAS. At 60 DAS, interaction $S10^{-4}M$ GA_3 x $F10^{-4}M$ GA_3 gave the maximum value. However, its effect was at par with that of $S10^{-6}M$ GA_3 x $F10^{-4}M$ GA_3, $S10^{-4}M$ GA_3 x $F10^{-6}M$ GA_3 and $S10^{-6}M$ GA_3 x $F10^{-6}M$ GA_3. Interaction $S10^{-6}M$ GA_3 x $F10^{-6}M$ GA_3 gave 24% higher value than the control at this stage (Table 22).

4.2.2.2 Carbonic anhydrase activity

Of the pre-sowing seed treatments, $S10^{-6}M$ GA_3 proved best at each stage. However, the effect of this treatment was equal to that of $S10^{-4}M$ GA_3 at both stages. Soaking treatment $S10^{-6}$ M GA_3 increased carbonic anhydrase

Table 22. Effect of pre-sowing seed treatment and foliar application of GA_3 on net photosynthetic rate [μ mol $(CO_2)/m^2/s$] of mustard variety Rohini at two stages of growth (mean of four replicates)

Foliar (F) treatments (M GA_3)	**Soaking (S) treatments (M GA_3)**				**Mean**
	0	10^{-8}	10^{-6}	10^{-4}	
			50 DAS		
0	14.45	15.17	15.43	15.32	15.09
10^{-8}	15.24	15.80	16.21	16.00	15.81
10^{-6}	15.89	16.22	17.66	17.51	16.82
10^{-4}	16.03	16.37	17.92	17.72	17.01
Mean	15.40	15.89	16.81	16.64	
CD at 5%	S=0.50		F = 0.50	SxF = NS	
			60 DAS		
0	15.74	16.68	16.84	17.01	16.57
10^{-8}	16.84	17.47	17.87	18.20	17.60
10^{-6}	17.58	18.16	19.52	19.64	18.73
10^{-4}	17.82	18.35	19.71	19.95	18.96
Mean	17.00	17.67	18.49	18.70	
CD at 5%	S=0.50		F = 0.50	SxF = 1.00	

NB : A uniform basal dose of $N_{90}P_{30}K_{30}$ was applied

activity by 9.3 and 9.3% at 50 and 60 DAS respectively over the water-soaked treatment.

At both stages, foliar treatment F10^{-6}M GA_3 proved best. However, its effect was at par with that of F10^{-4}M GA_3. Spray treatment F10^{-6}M GA_3 gave 12.4 and 12.2% higher enzyme activity at 50 and 60 DAS respectively than the water-sprayed treatment.

Effect of interactions (pre-sowing seed treatment x foliar spray treatment) was found non-significant on this parameter at both stages (Table 23).

4.2.2.3 Nitrate reductase activity

At both stages, pre-sowing seed treatment S10^{-6}M GA_3 proved best. However, the effect of this treatment was at par with that S10^{-4}M GA_3. Soaking treatment S10^{-6}M GA_3 increased the enzyme activity by 6.0 and 7.0% at 50 and 60 DAS respectively over the water-soaked treatment.

Among foliar treatments, F10^{-6}M GA_3 proved best but its effect was at par with that of F10^{-4}M GA_3 at both stages. Spray treatment F10^{-6}M GA_3 gave 9.8 and 12.3% higher enzyme activity at 50 and 60 DAS respectively than the water-sprayed treatment.

Effect of interactions (soaking treatment x spray treatment) was non-significant on this parameter at both stages (Table 24).

4.2.2.4 Leaf chlorophyll content

Of the pre-sowing seed treatments, S10^{-6}M GA_3 proved best at each stage. However, the effect of this treatment was at par with that of S10^{-4}M GA_3 at both stages. Soaking treatment S10^{-6}M GA_3 gave 10.1 and 12.7%

Table 23. Effect of pre-sowing seed treatment and foliar application of GA_3 on carbonic anhydrase activity [mol (CO_2)/kg (f.m.)/s] of mustard variety Rohini at two stages of growth (mean of four replicates)

Foliar (F) treatments (M GA_3)	**Soaking (S) treatments (M GA_3)**				**Mean**
	0	10^{-8}	10^{-6}	10^{-4}	
			50 DAS		
0	1.70	1.78	1.80	1.82	1.78
10^{-8}	1.81	1.87	1.94	1.91	1.88
10^{-6}	1.87	1.95	2.09	2.10	2.00
10^{-4}	1.89	1.99	2.13	2.11	2.03
Mean	1.82	1.90	1.99	1.99	
CD at 5%	S=0.04	F = 0.04		SxF = NS	
			60 DAS		
0	1.82	1.89	1.94	1.92	1.89
10^{-8}	1.92	1.97	2.05	2.03	1.99
10^{-6}	1.99	2.06	2.22	2.19	2.12
10^{-4}	2.00	2.09	2.24	2.23	2.14
Mean	1.93	2.00	2.11	2.09	
CD at 5%	S=0.03	F = 0.03		SxF = NS	

NB : A uniform basal dose of $N_{90}P_{30}K_{30}$ was applied

Table 24. Effect of pre-sowing seed treatment and foliar application of GA_3 on nitrate reductase activity [n mol (NO_2)/g(f.m.)/h] of mustard variety Rohini at two stages of growth (mean of four replicates)

Foliar (F) treatments (M GA_3)	**Soaking (S) treatments (M GA_3)**				**Mean**
	0	10^{-8}	10^{-6}	10^{-4}	
			50 DAS		
0	278.17	287.91	290.69	293.60	287.59
10^{-8}	293.47	300.42	305.99	309.05	302.23
10^{-6}	301.81	308.23	325.46	326.98	315.62
10^{-4}	306.43	310.66	328.59	329.63	318.83
Mean	294.97	301.81	312.68	314.82	
CD at 5%	S=6.90	F = 6.90		SxF = NS	
			60 DAS		
0	305.25	314.41	320.51	325.32	316.37
10^{-8}	323.57	335.25	344.15	352.70	338.92
10^{-6}	338.83	346.41	366.30	369.23	355.19
10^{-4}	342.94	350.50	370.79	372.41	359.16
Mean	327.65	336.64	350.44	354.92	
CD at 5%	S=6.90	F = 6.90		SxF = NS	

NB : A uniform basal dose of $N_{90}P_{30}K_{30}$ was applied

more chlorophyll content at 50 and 60 DAS respectively than the water-soaked treatment.

At both stages, foliar treatment F10^{-6}M GA_3 proved best. However, its effect was at par with that of F10^{-4}M GA_3. Spray treatment F10^{-6}M GA_3 gave 15.7 and 22.6% higher value at 50 and 60 DAS respectively than the water-sprayed treatment.

Interaction S10^{-4}M GA_3 x F10^{-4}M GA_3 gave the maximum value at both stages. However, its effect was at par with that of S10^{-4}M GA_3 x F10^{-6} M GA_3, S10^{-6}M GA_3 x F10^{-4}M GA_3 and S10^{-6}M GA_3 x F10^{-6}M GA_3 at both stages. Interaction S10^{-6}M GA_3 x F10^{-6}M GA_3 gave 27.1 and 36.7% higher value than the control (Table 25).

4.2.2.5 Leaf NPK content

At both stages, the effect of pre-sowing seed treatment and foliar treatment of GA_3, alone as well as in combination, was found to be non-significant (Tables 26-28).

4.2.3 Yield parameters

The effect of pre-sowing seed treatment and foliar treatment with GA_3, alone as well as in combination, on all yield parameters was found to be significant, except on seed number per pod, 1000-seed weight and oil content (Tables 29-31).

4.2.3.1 Pod number per plant

Pre-sowing seed treatment S10^{-6}M GA_3 proved best. However, the effect of this treatment was at par with that of S10^{-4}M GA_3. Soaking treatment S10^{-6}M GA_3 increased pod number per plant by 8.3% compared with the water-soaked treatment.

Table 25. Effect of pre-sowing seed treatment and foliar application of GA_3 on leaf chlorophyll content (g/kg) of mustard variety Rohini at two stages of growth (mean of four replicates)

Foliar (F) treatments (M GA_3)	**Soaking (S) treatments (M GA_3)**				**Mean**
	0	10^{-8}	10^{-6}	10^{-4}	
			50 DAS		
0	1.279	1.343	1.369	1.375	1.342
10^{-8}	1.369	1.400	1.460	1.452	1.420
10^{-6}	1.431	1.510	1.625	1.645	1.554
10^{-4}	1.439	1.521	1.631	1.648	1.558
Mean	1.380	1.444	1.521	1.530	
CD at 5%	S=0.05		F = 0.05	SxF = 0.10	
			60 DAS		
0	1.352	1.420	1.474	1.489	1.434
10^{-8}	1.460	1.501	1.595	1.643	1.550
10^{-6}	1.615	1.707	1.848	1.862	1.758
10^{-4}	1.568	1.698	1.839	1.857	1.741
Mean	1.499	1.582	1.689	1.713	
CD at 5%	S=0.06		F = 0.06	SxF = 0.12	

NB : A uniform basal dose of $N_{90}P_{30}K_{30}$ was applied

Table 26. Effect of pre-sowing seed treatment and foliar application of GA_3 on leaf nitrogen content (%) of mustard variety Rohini at two stages of growth (mean of four replicates)

Foliar (F) treatments (M GA_3)	**Soaking (S) treatments (M GA_3)**				**Mean**
	0	10^{-8}	10^{-6}	10^{-4}	
			50 DAS		
0	3.10	3.20	3.26	3.32	3.22
10^{-8}	3.30	3.36	3.43	3.48	3.40
10^{-6}	3.37	3.46	3.69	3.71	3.56
10^{-4}	3.41	3.50	3.73	3.76	3.60
Mean	3.29	3.38	3.53	3.57	
CD at 5%	S=NS	F = NS		SxF =NS	
			60 DAS		
0	2.85	2.91	2.96	2.99	2.93
10^{-8}	2.99	3.05	3.08	3.10	3.06
10^{-6}	3.05	3.09	3.29	3.31	3.19
10^{-4}	3.07	3.11	3.32	3.34	3.21
Mean	2.99	3.04	3.16	3.19	
CD at 5%	S=NS	F = NS		SxF =NS	

NB : A uniform basal dose of $N_{90}P_{30}K_{30}$ was applied

Table 27. Effect of pre-sowing seed treatment and foliar application of GA_3 on leaf phosphorus content (%) of mustard variety Rohini at two stages of growth (mean of four replicates)

Foliar (F) treatments (M GA_3)	**Soaking (S) treatments (M GA_3)**				**Mean**
	0	10^{-8}	10^{-6}	10^{-4}	
			50 DAS		
0	0.289	0.303	0.287	0.308	0.297
10^{-8}	0.280	0.279	0.285	0.309	0.288
10^{-6}	0.295	0.305	0.294	0.318	0.303
10^{-4}	0.299	0.304	0.296	0.317	0.304
Mean	0.291	0.298	0.291	0.313	
CD at 5%	S=NS	F = NS		SxF =NS	
			60 DAS		
0	0.273	0.270	0.272	0.281	0.274
10^{-8}	0.272	0.269	0.276	0.275	0.273
10^{-6}	0.268	0.266	0.265	0.274	0.268
10^{-4}	0.270	0.268	0.275	0.275	0.272
Mean	0.271	0.268	0.272	0.276	
CD at 5%	S=NS	F = NS		SxF =NS	

NB : A uniform basal dose of $N_{90}P_{30}K_{30}$ was applied

Table 28. Effect of pre-sowing seed treatment and foliar application of GA_3 on leaf potassium content (%) of mustard variety Rohini at two stages of growth (mean of four replicates)

Foliar (F) treatments (M GA_3)	**Soaking (S) treatments (M GA_3)**				**Mean**
	0	10^{-8}	10^{-6}	10^{-4}	
			50 DAS		
0	3.96	3.99	4.01	4.00	3.99
10^{-8}	4.00	4.02	4.04	4.02	4.02
10^{-6}	4.03	4.05	4.06	4.03	4.04
10^{-4}	4.02	4.03	4.04	4.02	4.03
Mean	4.00	4.02	4.04	4.02	
CD at 5%	S=NS		F = NS	SxF =NS	
			60 DAS		
0	3.80	3.83	3.85	3.84	3.83
10^{-8}	3.83	3.87	3.90	3.88	3.87
10^{-6}	3.87	3.91	3.92	3.91	3.90
10^{-4}	3.86	3.90	3.91	3.90	3.89
Mean	3.84	3.88	3.90	3.88	
CD at 5%	S=NS		F = NS	SxF =NS	

NB : A uniform basal dose of $N_{90}P_{30}K_{30}$ was applied

Among foliar treatments, $F10^{-6}M$ GA_3 proved best; but its effect was at par with that of $F10^{-4}M$ GA_3. Spray treatment $F10^{-6}M$ GA_3 produced 10.2% more pods than the water-sprayed treatment.

Interaction $S10^{-6}M$ GA_3 x $F10^{-4}M$ GA_3 gave the maximum value. However, its effect was at par with that of $S10^{-4}M$ GA_3 x $F10^{-6}M$ GA_3, $S10^{-4}$ M GA_3 x $F10^{-4}M$ GA_3 and $S10^{-6}M$ GA_3 x $F10^{-6}M$ GA_3. Interaction $S10^{-6}M$ GA_3 x $F10^{-6}M$ GA_3 gave 16.7% higher value than the control (Table 29).

4.2.3.2 Seed number per pod

Effect of pre-sowing seed treatment and foliar treatment of GA_3, alone as well as in combination, was found to be non-significant on this parameter (Table 29).

4.2.3.3 1000-seed weight

A non-significant effect, as was observed on seed number per pod, was also noticed on test weight (Table 30).

4.2.3.4 Seed yield per plant

Of the pre-sowing seed treatments, $S10^{-6}M$ GA_3 proved best. However, the effect of this treatment was at par with that of $S10^{-4}M$ GA_3. Soaking treatment $S10^{-6}M$ GA_3 gave 7.0% higher seed yield than the water-soaked treatment.

Foliar treatment $F10^{-6}M$ GA_3 proved best, with $F10^{-4}M$ GA_3 giving equal effect. Spray treatment $F10^{-6}M$ GA_3 increased seed yield per plant by 9.2% over the water-sprayed treatment.

Table 29. Effect of pre-sowing seed treatment and foliar application of GA_3 on pod number per plant and seed number per pod of mustard variety Rohini at harvest (mean of four replicates)

Foliar (F) treatments (M GA_3)	**Soaking (S) treatments (M GA_3)**				**Mean**
	0	10^{-8}	10^{-6}	10^{-4}	
			Pod number per plant		
0	105.00	106.75	107.50	108.00	106.81
10^{-8}	107.75	109.00	112.50	113.50	110.69
10^{-6}	109.50	114.75	122.50	124.00	117.69
10^{-4}	110.00	113.50	125.50	123.75	118.19
Mean	108.06	111.00	117.00	117.31	
CD at 5%	S=5.31		F = 5.31	SxF =10.62	
			Seed number per pod		
0	12.75	12.00	12.00	12.00	12.19
10^{-8}	11.75	11.50	11.00	11.75	11.50
10^{-6}	12.00	11.75	11.75	11.75	11.81
10^{-4}	13.00	12.00	12.50	12.50	12.50
Mean	12.38	11.81	11.81	12.00	
CD at 5%	S=NS		F = NS	SxF =NS	

NB : A uniform basal dose of $N_{90}P_{30}K_{30}$ was applied

Table 30. Effect of pre-sowing seed treatment and foliar application of GA_3 on 1000-seed weight and seed yield per plant of mustard variety Rohini at harvest (mean of four replicates)

Foliar (F) treatments (M GA_3)	**Soaking (S) treatments (M GA_3)**				**Mean**
	0	10^{-8}	10^{-6}	10^{-4}	
			1000-seed weight (g)		
0	4.23	4.14	4.15	4.18	4.18
10^{-8}	4.35	4.29	4.32	4.30	4.32
10^{-6}	4.36	4.27	4.31	4.28	4.31
10^{-4}	4.32	4.35	4.30	4.35	4.33
Mean	4.32	4.26	4.27	4.28	
CD at 5%	S=NS		F = NS	SxF =NS	
			Seed yield per plant (g)		
0	7.21	7.38	7.43	7.47	7.37
10^{-8}	7.41	7.64	7.71	7.81	7.64
10^{-6}	7.62	7.74	8.40	8.43	8.05
10^{-4}	7.68	7.83	8.47	8.51	8.12
Mean	7.48	7.65	8.00	8.06	
CD at 5%	S=0.27		F = 0.27	SxF =0.54	

NB : A uniform basal dose of $N_{90}P_{30}K_{30}$ was applied

Interaction $S10^{-4}M$ GA_3 x $F10^{-4}M$ GA_3 gave maximum seed yield. However, the effect of this treatment was at par with that of $S10^{-6}M$ GA_3 x $F10^{-4}M$ GA_3, $S10^{-4}M$ GA_3 x $F10^{-6}M$ GA_3 and $S10^{-6}M$ GA_3 x $F10^{-6}M$ GA_3. Interaction $S10^{-6}M$ GA_3 x $F10^{-6}M$ GA_3 gave 16.5% higher value for seed yield than the control (Table 30).

4.2.3.5 Oil content

The effect of pre-sowing seed treatment and foliar treatment with GA_3, alone as well as in combination was found non-significant on this parameter (Table 31).

4.2.3.6 Oil yield per plant

Among pre-sowing seed treatments, $S10^{-6}M$ GA_3 proved best. However, the effect was at par with that of $S10^{-4}M$ GA_3. Soaking treatment $S10^{-6}M$ GA_3 gave 7.8% higher oil yield than the water- soaked treatment.

Foliar treatment $F10^{-4}M$ GA_3 gave the maximum value. The effect of this treatment was followed by that of $F10^{-6}M$ GA_3 and $F10^{-8}M$ GA_3. Spray treatment $F10^{-6}M$ GA_3 gave 6.8% higher value than the water-sprayed treatment.

Interaction $S10^{-4}M$ GA_3 x $F10^{-4}M$ GA_3 gave the maximum value. However, its effect was at par with that of $S10^{-6}M$ GA_3 x $F10^{-4}M$ GA_3, $S10^{-4}$ M GA_3 x $F10^{-6}M$ GA_3 and $S10^{-6}M$ GA_3 x $F10^{-6}M$ GA_3. Interaction $S10^{-6}M$ GA_3 x $F10^{-6}M$ GA_3 increased oil yield by 11.3% over the control (Table 31).

4.2.4 Quality parameters

The effect of pre-sowing seed treatment and foliar treatment with GA_3, alone as well as in combination, on acid, iodine and saponification value was found to be non-significant (Table 32).

Table 31. Effect of pre-sowing seed treatment and foliar application of GA_3 on seed oil content and oil yield per plant of mustard variety Rohini at harvest (mean of four replicates)

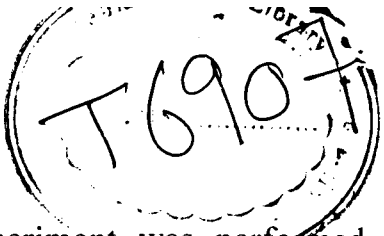
Foliar (F) treatments (M GA_3)	**Soaking (S) treatments (M GA_3)**				**Mean**
	0	10^{-8}	10^{-6}	10^{-4}	
			Oil content (%)		
0	36.51	33.90	35.70	36.42	35.63
10^{-8}	35.43	34.43	36.75	37.01	35.91
10^{-6}	34.64	33.68	35.16	36.36	34.96
10^{-4}	36.73	35.32	36.93	37.19	36.54
Mean	35.83	34.33	36.14	36.75	
CD at 5%	S=NS	F = NS		SxF =NS	
			Oil yield per plant (g)		
0	2.65	2.50	2.65	2.73	2.63
10^{-8}	2.64	2.66	2.85	2.89	2.76
10^{-6}	2.62	2.62	2.95	3.06	2.81
10^{-4}	2.85	2.75	3.14	3.17	2.98
Mean	2.69	2.63	2.90	2.96	
CD at 5%	S=0.12	F = 0.12		SxF =0.24	

NB : A uniform basal dose of $N_{90}P_{30}K_{30}$ was applied

Table 32. Effect of pre-sowing seed treatment and foliar application of GA_3 on acid, iodine and saponification value of mustard variety Rohini at harvest (mean of four replicates)

Foliar (F) treatments (M GA_3)	**Soaking (S) treatments (M GA_3)**				**Mean**
	0	10^{-8}	10^{-6}	10^{-4}	
			Acid value		
0	4.08	4.24	4.37	4.20	4.22
10^{-8}	4.17	4.28	4.41	4.42	4.32
10^{-6}	4.23	4.31	4.48	4.45	4.37
10^{-4}	4.15	4.25	4.54	4.56	4.38
Mean	4.16	4.27	4.45	4.41	
CD at 5%	S=NS	F = NS		SxF =NS	
			Iodine value		
0	98.77	98.85	97.53	99.24	98.60
10^{-8}	96.27	97.15	98.33	99.85	97.90
10^{-6}	97.59	96.75	99.94	100.15	98.61
10^{-4}	98.98	99.16	101.85	102.03	100.51
Mean	97.90	97.98	99.41	100.32	
CD at 5%	S=NS	F = NS		SxF =NS	
			Saponification value		
0	178.57	165.35	163.22	161.93	167.27
10^{-8}	181.08	170.92	169.50	165.70	171.80
10^{-6}	189.64	176.81	175.73	173.55	178.93
10^{-4}	190.05	177.28	176.58	173.35	179.32
Mean	184.84	172.59	171.26	168.63	
CD at 5%	S=NS	F = NS		SxF =NS	

NB : A uniform basal dose of $N_{90}P_{30}K_{30}$ was applied



4.3 Experiment 3

This factorial randomized design experiment was performed to determine the N and P requirement of mustard (*Brassica juncea* L. Czern. & Coss.) variety Rohini grown with the best combination of soaking and spray with GA_3, determined in Experiment 2. The parameters studied were the same as in Experiment 2. The results (Tables 33-47) are described briefly below.

4.3.1 Growth parameters

Effect of basal application of N and P, alone as well as in combination, was significant on all growth parameters studied at 50 and 60 DAS (Tables 33-36).

4.3.1.1 Shoot length per plant

At both stages, application of basal N at N_{90} proved best. However, its effect was at par with that of N_{120}. Treatment N_{90} increased shoot length per plant by 13.7 and 15.3% at 50 and 60 DAS respectively than N_0.

Among basal P treatments, P_{30} proved best at both stages, but its effect was at par with that of P_{45}. Application of P_{30} resulted in 5.8 and 8.1% higher shoot length at 50 and 60 DAS respectively than P_0.

At 50 DAS, interaction N_{120} x P_{30} gave maximum value. However, its effect was at par with that of N_{90} x P_{45}, N_{120} x P_{45}, N_{90} x P_{30}, N_{120} x P_{15}, N_{90} x P_{15}, N_{60} x P_{45}, N_{60} x P_{30} and P_{120} x P_0. At 60 DAS, N_{120} x P_{45} gave maximum shoot length; but the effect of this treatment was equalled by that of N_{120} x P_{30}, N_{90} x P_{30} and N_{90} x P_{45}. Interaction N_{90} x P_{30} gave 19. 8 and 24.9% higher shoot length at 50 and 60 DAS respectively than N_0 x P_0, i.e. control (Table 33).

Table 33. Effect of basal N and P on shoot length per plant (cm) of mustard variety Rohini at two stages of growth (Mean of four replicates)

P treatments (kg/ha)	N treatments (kg/ha)					Mean
	0	30	60	90	120	
			50 DAS			
0	41.9	43.9	45.2	46.5	46.9	44.88
15	42.3	44.3	46.2	47.8	48.1	45.74
30	43.6	45.5	47.1	50.2	51.0	47.48
45	44.0	45.1	47.4	50.8	50.7	47.60
Mean	42.95	44.70	46.48	48.83	49.18	
CD at 5%	N = 1.44		P=1.29		NxP=4.10	
			60 DAS			
0	43.8	45.8	46.9	48.1	48.5	46.62
15	44.7	46.6	47.9	49.5	49.9	47.72
30	45.5	47.8	49.0	54.7	54.9	50.38
45	45.3	48.4	49.4	54.4	55.1	50.52
Mean	44.83	47.15	48.30	51.68	52.10	
CD at 5%	N=1.72		P=1.54		NxP=3.45	

NB : (i) A uniform dose of 30 kg K/ha was applied at the time of sowing

(ii) Seeds were soaked with 10^{-6}M GA_3 solution for 8 h before sowing and the plants grown from these seeds were sprayed with the same concentration of GA_3 at 40 DAS

4.3.1.2 Leaf area per plant

Of the N treatments, N_{90} proved best at each stage. However, the effect of this treatment was at par with that of N_{120} at both stages. Treatment N_{90} gave 9.1 and 5.2% more leaf area at 50 and 60 DAS respectively than N_0.

At both stages, application of P_{30} proved best. However, its effect was at par with that of P_{45}. Treatment P_{30} gave 6.5 and 5.2% higher value at 50 and 60 DAS respectively than P_0.

Interactions N_{120} x P_{30}, N_{120} x P_{45}, N_{90} x P_{45} and N_{90} x P_{30}, being at par, gave maximum value at both stages. Interaction N_{90} x P_{30} increased leaf area per plant by 15.9 and 12.4% at 50 and 60 DAS respectively over the control (Table 34).

4.3.1.3 Fresh weight per plant

At both stages, application of N_{90} proved best. However, the effect of this treatment was at par with that of N_{120} at each stage. Treatment N_{90} gave 11.0 and 13.5% more fresh matter at 50 and 60 DAS respectively than N_0.

Treatment P_{45} and P_{30}, being at par, gave higher value than the other P treatments at each stage. Application of P_{30} resulted in 7.3 and 7.7% higher value at 50 and 60 DAS respectively than P_0.

At both stages, interaction N_{120} x P_{45} gave maximum value. However, the effect of this treatment was at par with that of N_{90} x P_{45}, N_{120} x P_{30} and N_{90} x P_{30}. Interaction N_{90} x P_{30} increased fresh weight by 18.7 and 22.5% at 50 and 60 DAS respectively compared with the control (Table 35).

Table 34. Effect of basal N and P on leaf area per plant (cm^2) of mustard variety Rohini at two stages of growth (Mean of four replicates)

P treatments (kg/ha)	N treatments (kg/ha)					Mean
	0	30	60	90	120	
			50 DAS			
0	458.2	460.5	463.8	470.7	472.8	465.20
15	459.0	462.8	466.2	479.5	481.8	469.86
30	461.3	466.9	483.2	531.2	533.5	495.22
45	465.4	463.6	485.5	530.8	534.1	495.88
Mean	460.98	463.45	474.68	503.05	505.55	
CD at 5%	N = 20.34		P=19.23		NxP=40.95	
			60 DAS			
0	487.1	487.9	488.4	491.5	491.9	489.36
15	487.6	488.4	489.7	492.6	493.2	490.30
30	488.7	494.6	491.2	547.4	551.4	514.66
45	489.5	490.3	498.1	548.7	549.2	515.16
Mean	488.23	490.30	491.85	520.05	521.43	
CD at 5%	N=21.89		P=20.35		NxP=44.66	

NB : (i) A uniform dose of 30 kg K/ha was applied at the time of sowing

(ii) Seeds were soaked with 10^{-6}M GA_3 solution for 8 h before sowing and the plants grown from these seeds were sprayed with the same concentration of GA_3 at 40 DAS

Table 35. Effect of basal N and P on fresh weight per plant (g) of mustard variety Rohini at two stages of growth (Mean of four replicates)

P treatments (kg/ha)	N treatments (kg/ha)					Mean
	0	30	60	90	120	
			50 DAS			
0	7.29	7.41	7.52	7.68	7.70	7.52
15	7.35	7.50	7.65	7.79	7.83	7.62
30	7.40	7.71	7.96	8.65	8.61	8.07
45	7.42	7.60	7.90	8.59	8.69	8.04
Mean	7.37	7.56	7.76	8.18	8.21	
CD at 5%	N = 0.28		P=0.25		NxP=0.55	
			60 DAS			
0	7.96	8.25	8.38	8.69	8.76	8.41
15	8.12	8.32	8.64	8.79	8.88	8.55
30	8.23	8.51	9.00	9.75	9.81	9.06
45	8.35	8.62	9.09	9.86	9.90	9.16
Mean	8.17	8.43	8.78	9.27	9.34	
CD at 5%	N=0.30		P=0.27		NxP=0.59	

NB : (i) A uniform dose of 30 kg K/ha was applied at the time of sowing

(ii) Seeds were soaked with 10^{-6}M GA_3 solution for 8 h before sowing and the plants grown from these seeds were sprayed with the same concentration of GA_3 at 40 DAS

4.3.1.4 Dry weight per plant

Of the N treatments, N_{90} proved best at both stages, with N_{120} giving equal values. Treatments N_{90} produced 7.4 and 9.0% more dry matter at 50 and 60 DAS respectively than N_0.

At each stage, treatment P_{45} and P_{30}, being at par, gave higher value than the other P treatments. P treatment P_{30} gave 4.8 and 5.4% higher dry weight at 50 and 60 DAS respectively than P_0.

Interactions N_{120} x P_{30}, N_{120} x P_{45}, N_{90} x P_{45} and N_{90} x P_{30}, being at par, gave higher value than the other interaction treatments at both stages. Interaction N_{90} x P_{30} gave 13.5 and 15.1% higher value at 50 and 60 DAS respectively than the control (Table 36).

4.3.2 Physiological and bio-chemical parameters

The effect of basal application of N and P, alone as well in combination, was significant at both stages on all parameters studied, except leaf K content. A non-significant effect was also observed at each stage due to N application alone on P content, P application alone on nitrate reductase activity and N content and N and P application in combination (interaction) on carbonic anhydrase activity, nitrate reductase activity and N and P content. Moreover, net photosynthetic rate at 50 DAS and chlorophyll content at 60 DAS were not affected by the combined application of N and P (Tables 37-43).

4.3.2.1 Net photosynthetic rate

Of the N treatments, N_{90} proved best at each stage. However, the effect of this treatment was at par with that of N_{120} at both stages. Treatment

Table 36. Effect of basal N and P on dry weight per plant (g) of mustard variety Rohini at two stages of growth (Mean of four replicates)

P treatments (kg/ha)	N treatments (kg/ha)					Mean
	0	30	60	90	120	
			50 DAS			
0	2.67	2.71	2.75	2.78	2.79	2.74
15	2.69	2.72	2.77	2.80	2.82	2.76
30	2.73	2.76	2.79	3.03	3.05	2.87
45	2.74	2.79	2.81	3.04	3.07	2.89
Mean	2.71	2.75	2.78	2.91	2.93	
CD at 5%	N = 0.09		P=0.08		NxP=0.18	
			60 DAS			
0	2.84	2.90	2.95	2.99	3.02	2.94
15	2.87	2.94	2.97	3.04	3.06	2.98
30	2.92	2.96	3.01	3.27	3.33	3.10
45	2.91	2.99	3.05	3.30	3.31	3.11
Mean	2.89	2.95	3.00	3.15	3.18	
CD at 5%	N=0.09		P=0.07		NxP=0.17	

NB : (i) A uniform dose of 30 kg K/ha was applied at the time of sowing

(ii) Seeds were soaked with 10^{-6}M GA_3 solution for 8 h before sowing and the plants grown from these seeds were sprayed with the same concentration of GA_3 at 40 DAS

N_{90} gave 10.7 and 12.8% higher net photosynthetic rate at 50 and 60 DAS respectively than N_0.

At both stages, application of P_{30} proved best. However, its effect was at par with that of P_{45}. Treatment P_{30} increased the net photosynthetic rate by 4.9 and 6.4% at 50 and 60 DAS respectively over P_0.

The interaction effect on this parameter at 50 DAS was found non-significant. At 60 DAS, interaction N_{120} x P_{30} gave maximum value. However, the effect of this treatment was at par with that of N_{120} x P_{45}, N_{90} x P_{30} and N_{90} x P_{45}. Interaction N_{90} x P_{30} increased net photosynthetic rate by 20.6% at this stage compared with the control (Table 37).

4.3.2.2 Carbonic anhydrase activity

At both stages, application of N_{90} proved best. However, the effect of this treatment was at par with that of N_{120}. Treatment N_{90} gave 13.2 and 12.9% higher enzyme activity at 50 and 60 DAS respectively than N_0.

Treatments P_{30} and P_{45}, being at par, gave higher value than the other P treatments at each stage. Application of P_{30} resulted in 7.3 and 6.0% higher value at 50 and 60 DAS respectively than P_0.

The effect of interactions (N x P) was non-significant at both stages (Table 38).

4.3.2.3 Nitrate reductase activity

Of the N treatments, N_{90} proved best at both stages, with N_{120} giving equal value. Treatment N_{90} gave 10.2 and 12.4% higher enzyme activity at 50 and 60 DAS respectively than N_0.

Table 37. Effect of basal N and P on net photosynthetic rate [μ mol $(CO_2)/m^2/s$] of mustard variety Rohini at two stages of growth (Mean of four replicates)

P treatments (kg/ha)	N treatments (kg/ha)					Mean
	0	30	60	90	120	
			50 DAS			
0	17.27	18.01	18.38	18.49	18.65	18.16
15	17.51	18.29	18.44	18.78	18.94	18.39
30	17.68	18.40	18.64	20.12	20.40	19.05
45	17.75	18.53	18.91	20.28	20.55	19.20
Mean	17.55	18.31	18.59	19.42	19.64	
CD at 5%	N = 0.52		P=0.47		NxP=NS	
			60 DAS			
0	19.14	20.14	20.44	20.77	20.98	20.29
15	19.52	20.15	20.64	21.35	21.53	20.64
30	19.91	20.63	21.00	23.08	23.35	21.59
45	19.57	20.50	20.77	22.97	23.20	21.40
Mean	19.54	20.36	20.71	22.04	22.27	
CD at 5%	N=0.59		P=0.52		NxP=1.17	

NB : (i) A uniform dose of 30 kg K/ha was applied at the time of sowing

(ii) Seeds were soaked with 10^{-6}M GA_3 solution for 8 h before sowing and the plants grown from these seeds were sprayed with the same concentration of GA_3 at 40 DAS

Table 38. Effect of basal N and P on carbonic anhydrase activity [mol (CO_2)/kg (f.m.)/s] of mustard variety Rohini at two stages of growth (Mean of four replicates)

P treatments (kg/ha)	N treatments (kg/ha)					Mean
	0	30	60	90	120	
			50 DAS			
0	2.06	2.18	2.22	2.24	2.25	2.19
15	2.09	2.20	2.23	2.37	2.41	2.26
30	2.15	2.24	2.31	2.49	2.55	2.35
45	2.18	2.22	2.36	2.51	2.54	2.36
Mean	2.12	2.21	2.28	2.40	2.44	
CD at 5%	N = 0.05		P=0.05		NxP=NS	
			60 DAS			
0	2.21	2.33	2.37	2.42	2.44	2.35
15	2.23	2.35	2.40	2.51	2.54	2.41
30	2.27	2.42	2.53	2.61	2.64	2.49
45	2.28	2.37	2.50	2.62	2.65	2.48
Mean	2.25	2.37	2.45	2.54	2.57	
CD at 5%	N=0.05		P=0.05		NxP=NS	

NB : (i) A uniform dose of 30 kg K/ha was applied at the time of sowing

(ii) Seeds were soaked with 10^{-6}M GA_3 solution for 8 h before sowing and the plants grown from these seeds were sprayed with the same concentration of GA_3 at 40 DAS

Application of P alone proved ineffective on this parameter at both stages.

The effect of interactions (N x P) was also non-significant at both stages (Table 39).

4.3.2.4 Leaf chlorophyll content

Of the N treatments, N_{90} proved best at both stages, with N_{120} giving equal value. Treatment N_{90} gave 13.9 and 11.7% higher chlorophyll content at 50 and 60 DAS respectively than N_0.

At each stage, P_{45} and P_{30}, being at par, gave higher value than the other P treatments. P treatment P_{30} gave 7.1 and 6.2% higher value at 50 and 60 DAS respectively than P_0.

At 50 DAS, interaction N_{120} x P_{45} gave maximum value. However, the effect of this treatment was at par with that of N_{120} x P_{30}, N_{90} x P_{45} and N_{90} x P_{30}. Interaction N_{90} x P_{30} increased leaf chlorophyll content by 21.3% at this stage compared with the control. However, at 60 DAS, the interaction effect was non-significant (Table 40).

4.3.2.5 Leaf N content

At both stages, application of N_{90} proved best. However, the effect of this treatment was at par with that of N_{120} at each stage. Treatment N_{90} gave 12.0 and 9.1% higher value at 50 and 60 DAS respectively than N_0.

The application of P did not affect this parameter at either stages.

The effect of interactions (N x P) was also found non-significant at both stages (Table 41).

Table 39. Effect of basal N and P on nitrate reductase activity [n mol (NO_2)/g(f.m.)/h] of mustard variety Rohini at two stages of growth (Mean of four replicates)

P treatments (kg/ha)	N treatments (kg/ha)					Mean
	0	30	60	90	120	
			50 DAS			
0	320.25	334.66	340.11	343.95	345.87	336.97
15	325.05	338.75	342.14	350.29	355.54	342.35
30	331.46	344.22	352.86	373.85	379.18	356.31
45	329.22	340.08	347.52	371.63	376.11	352.91
Mean	326.50	339.43	345.65	359.93	364.18	
CD at 5%	N = 8.01		P=NS		NxP=NS	
			60 DAS			
0	363.41	387.23	395.65	410.35	412.11	393.75
15	371.04	381.94	390.58	397.30	400.11	388.19
30	376.13	390.45	402.94	432.46	439.38	408. 27
45	381.09	392.40	409.79	436.79	443.36	412.69
Mean	372.92	388.01	399.74	419.23	423.74	
CD at 5%	N=8.18		P=NS		NxP=NS	

NB : (i) A uniform dose of 30 kg K/ha was applied at the time of sowing

(ii) Seeds were soaked with 10^{-6}M GA_3 solution for 8 h before sowing and the plants grown from these seeds were sprayed with the same concentration of GA_3 at 40 DAS

Table 40. Effect of basal N and P on leaf chlorophyll content (g/kg) of mustard variety Rohini at two stages of growth (Mean of four replicates)

P treatments (kg/ha)	N treatments (kg/ha)					Mean
	0	30	60	90	120	
			50 DAS			
0	1.646	1.720	1.740	1.809	1.816	1.747
15	1.679	1.734	1.783	1.871	1.882	1.790
30	1.709	1.769	1.852	1.997	2.024	1.870
45	1.718	1.796	1.871	2.016	2.058	1.892
Mean	1.688	1.755	1.812	1.923	1.945	
CD at 5%	N = 0.06		P=0.06		NxP=0.11	
			60 DAS			
0	1.815	1.882	1.915	1.940	1.957	1.902
15	1.840	1.900	1.934	1.968	2.000	1.928
30	1.860	1.929	1.957	2.160	2.192	2.020
45	1.871	1.946	1.986	2.184	2.201	2.038
Mean	1.847	1.914	1.948	2.063	2.088	
CD at 5%	N=0.06		P=0.06		NxP=NS	

NB : (i) A uniform dose of 30 kg K/ha was applied at the time of sowing

(ii) Seeds were soaked with 10^{-6}M GA_3 solution for 8 h before sowing and the plants grown from these seeds were sprayed with the same concentration of GA_3 at 40 DAS

Table 41. Effect of basal N and P on leaf nitrogen content (%) of mustard variety Rohini at two stages of growth (Mean of four replicates)

P treatments (kg/ha)	N treatments (kg/ha)					Mean
	0	30	60	90	120	
			50 DAS			
0	3.57	3.70	3.77	3.88	3.91	3.77
15	3.52	3.67	3.72	3.81	3.85	3.71
30	3.60	3.74	3.83	4.17	4.25	3.92
45	3.66	3.79	3.90	4.22	4.28	3.97
Mean	3.59	3.73	3.81	4.02	4.07	
CD at 5%	N = 0.10		P=NS		NxP=NS	
			60 DAS			
0	3.24	3.35	3.39	3.45	3.47	3.38
15	3.35	3.43	3.51	3.72	3.79	3.56
30	3.30	3.41	3.46	3.69	3.75	3.52
45	3.27	3.37	3.43	3.48	3.50	3.41
Mean	3.29	3.39	3.45	3.59	3.63	
CD at 5%	N=0.09		P=NS		NxP=NS	

NB : (i) A uniform dose of 30 kg K/ha was applied at the time of sowing

(ii) Seeds were soaked with 10^{-6}M GA_3 solution for 8 h before sowing and the plants grown from these seeds were sprayed with the same concentration of GA_3 at 40 DAS

4.3.2.6 Leaf P content

The P content of leaves was not influenced by N treatments at both stages.

Of the P treatments, P_{30} proved best at both stages, with P_{45} giving equal value. Treatment P_{30} gave 8.4 and 14.0% higher content at 50 and 60 DAS respectively than P_0.

At both stages, the interaction effect (N x P) was noted to be non-significant on this parameter (Table 42).

4.3.2.7 Leaf K content

At both stages, the effect of N and P application, alone as well as in combination, was non-significant on K content of leaves (Table 43).

4.3.3 Yield parameters

The effect of basal application of N and P, alone as well as in combination, was found significant on all yield parameters, except the individual effect of N on oil content and of P on seed number per pod and 1000-seed weight as was also the interaction effect (N x P) on seed number per pod, 1000-seed weight and oil percentage (Tables 44-46).

4.3.3.1 Pod number per plant

Of the N treatments, N_{90} proved best. However, the effect of this treatment was at par with that of N_{120}. Treatment N_{90} gave 8.7% higher pod number than N_0.

Application of P_{30} proved best, with P_{45} giving equal value. Treatment P_{30} increased the pod number per plant by 5.8% over P_0.

Table 42. Effect of basal N and P on leaf phosphorus content (%) of mustard variety Rohini at two stages of growth (Mean of four replicates)

P treatments (kg/ha)	N treatments (kg/ha)					Mean
	0	30	60	90	120	
			50 DAS			
0	0.302	0.293	0.286	0.272	0.279	0.286
15	0.305	0.295	0.287	0.275	0.280	0.288
30	0.331	0.320	0.311	0.297	0.291	0.310
45	0.335	0.327	0.315	0.301	0.308	0.317
Mean	0.318	0.309	0.300	0.286	0.290	
CD at 5%	N = NS		P=0.02		NxP=NS	
			60 DAS			
0	0.272	0.268	0.261	0.251	0.245	0.259
15	0.275	0.270	0.264	0.249	0.255	0.263
30	0.310	0.301	0.289	0.296	0.281	0.295
45	0.314	0.304	0.299	0.286	0.292	0.299
Mean	0.293	0.286	0.278	0.271	0.268	
CD at 5%	N=NS		P=0.03		NxP=NS	

NB : (i) A uniform dose of 30 kg K/ha was applied at the time of sowing

(ii) Seeds were soaked with 10^{-6}M GA_3 solution for 8 h before sowing and the plants grown from these seeds were sprayed with the same concentration of GA_3 at 40 DAS

Table 43. Effect of basal N and P on leaf potassium content (%) of mustard variety Rohini at two stages of growth (Mean of four replicates)

P treatments (kg/ha)	N treatments (kg/ha)					Mean
	0	30	60	90	120	
			50 DAS			
0	4.00	4.02	3.98	3.95	3.94	3.98
15	4.05	4.03	4.00	3.97	3.96	4.00
30	4.12	4.09	4.05	4.11	4.01	4.08
45	4.16	4.13	4.00	3.95	3.93	4.03
Mean	4.08	4.07	4.01	4.00	3.96	
CD at 5%	N = NS		P=NS		NxP=NS	
			60 DAS			
0	3.90	3.89	3.87	3.85	3.84	3.87
15	3.92	3.93	3.90	3.88	3.87	3.90
30	3.96	3.95	3.93	3.96	3.91	3.94
45	3.98	3.97	3.91	3.95	3.94	3.95
Mean	3.94	3.94	3.90	3.91	3. 89	
CD at 5%	N=NS		P=NS		NxP=NS	

NB : (i) A uniform dose of 30 kg K/ha was applied at the time of sowing

(ii) Seeds were soaked with 10^{-6}M GA_3 solution for 8 h before sowing and the plants grown from these seeds were sprayed with the same concentration of GA_3 at 40 DAS

The interaction N_{120} x P_{45} gave maximum value. However, the effect of this treatment was at par with that of N_{120} x P_{30}, N_{90} x P_{45} and N_{90} x P_{30}. Interaction N_{90} x P_{30} gave 14.7% higher value than the control (Table 44).

4.3.3.2 Seed number per pod

Treatment N_{120} and N_{90}, being at par, gave higher value than the other treatments. Application of N_{90} resulted in 7.1% higher seed number per pod than N_0.

The application of P proved ineffective on this parameter.

The interaction effect (N x P) was also found to be non-significant on this parameter (Table 44).

4.3.3.3 1000-seed weight

Of the N treatments, N_{90} proved best. However, the effect of this treatment was at par with that of N_{120}. Treatment N_{90} gave 5.7% higher seed weight than N_0.

The application of P could not influence this parameter.

The effect of the interactions (N x P) on test weight of seeds was noted to be also non-significant (Table 45).

4.3.3.4 Seed yield per plant

The N treatments N_{120} and N_{90}, being at par, gave higher value than the other treatments. Treatment N_{90} gave 11.7% higher seed yield than N_0.

Of the P treatments, P_{30} proved best. However, the effect of this treatment was at par with that of P_{45}. Treatment P_{30} increased seed yield by 5.3% in comparison with P_0.

Table 44. Effect of basal N and P on pod number per plant and seed number per pod of mustard variety Rohini at harvest (Mean of four replicates)

P treatments (kg/ha)	N treatments (kg/ha)					Mean
	0	30	60	90	120	
	Pod number per plant					
0	125.50	126.50	127.50	130.75	131.00	128.25
15	125.75	127.00	128.50	131.50	132.00	128.95
30	128.00	130.00	130.50	144.00	145.75	135.65
45	128.00	129.75	132.00	145.00	146.00	136.15
Mean	126.81	128.31	129.63	137.81	138.69	
CD at 5%	N = 5.49		P=5.10		NxP=10.98	
	Seed number per pod					
0	11.50	11.50	11.50	12.50	12.50	11.90
15	11.00	11.75	11.75	11.75	12.00	11.65
30	11.50	11.50	11.75	12.50	12.50	11.95
45	11.50	11.75	11.75	12.00	12.00	11.80
Mean	11.38	11.63	11.69	12.19	12.25	
CD at 5%	N=0.08		P=NS		NxP=NS	

NB : (i) A uniform dose of 30 kg K/ha was applied at the time of sowing

(ii) Seeds were soaked with 10^{-6}M GA_3 solution for 8 h before sowing and the plants grown from these seeds were sprayed with the same concentration of GA_3 at 40 DAS

Table 45. Effect of basal N and P on 1000-seed weight and seed yield of mustard variety Rohini at harvest (Mean of four replicates)

P treatments (kg/ha)	N treatments (kg/ha)					Mean
	0	30	60	90	120	
	1000-seed weight (g)					
0	3.87	3.91	3.93	4.07	4.09	3.97
15	3.89	3.93	3.95	4.09	4.13	4.00
30	3.90	3.95	3.97	4.12	4.14	4.02
45	3.91	3.97	3.98	4.14	4.16	4.03
Mean	3.89	3.94	3.96	4.11	4.13	
CD at 5%	N = 0.03		P=NS		NxP=NS	
	Seed yield per plant (g)					
0	8.57	8.96	9.11	9.28	9.30	9.04
15	8.64	9.05	9.21	9.35	9.38	9.13
30	8.78	9.17	9.30	10.11	10.25	9.52
45	8.84	9.24	9.36	10.19	10.28	9.58
Mean	8.71	9.11	9.25	9.73	9.80	
CD at 5%	N=0.35		P=0.31		NxP=0.69	

NB : (i) A uniform dose of 30 kg K/ha was applied at the time of sowing

(ii) Seeds were soaked with 10^{-6}M GA_3 solution for 8 h before sowing and the plants grown from these seeds were sprayed with the same concentration of GA_3 at 40 DAS

The interaction, N_{120} x P_{45} gave maximum value. However, the effect of this treatment was at par with that of N_{120} x P_{30}, N_{120} x P_{45} and N_{90} x P_{30}. Interaction N_{90} x P_{30} gave 18.0% higher value than the control (Table 45).

4.3.3.5 Oil content

The application of N did not affect this parameter.

The treatment P_{30} proved best, with P_{45} giving equal value. Treatment P_{30} gave 6.1% higher value than P_0.

The effect of interactions (N x P) was found non-significant on oil content of seeds (Table 46).

4.3.3.6 Oil yield per plant

Treatments N_{120}, N_{90} and N_{60}, being at par, gave higher value than the other treatments. Treatment N_{90} gave 8.7% higher oil yield per plant than N_0.

The application of P_{30} proved best, with P_{45} giving equal value. It increased oil yield per plant by 11.3% over P_0.

The interaction N_{120} x P_{45} gave maximum value. However, the effect of this treatment was at par with that of N_{90} x P_{45}, N_{120} x P_{30}, N_{90} x P_{30} and N_{60} x P_{45}. Interaction N_{90} x P_{30} gave 20.5% higher value than the control (Table 46).

4.3.4 Quality parameters

The individual effect of N and P treatments was found significant only on iodine and saponification value. However, interaction (N x P) effect was non-significant on all the three quality parameters (Table 47).

Table 46. Effect of basal N and P on seed oil content and oil yield per plant of mustard variety Rohini at harvest (Mean of four replicates)

P treatments (kg/ha)	N treatments (kg/ha)					Mean
	0	30	60	90	120	
			Oil content (%)			
0	35.63	35.33	35.01	34.75	34.62	35.07
15	36.52	36.25	35.83	35.54	35.50	35.93
30	38.15	37.73	37.09	36.61	36.41	37.20
45	37.73	37.45	37.32	36.90	36.63	37.21
Mean	37.01	36.69	36.31	35.95	35.79	
CD at 5%	N = NS		P=0.54		NxP=NS	
			Oil yield per plant (g)			
0	3.07	3.18	3.20	3.23	3.25	3.19
15	3.13	3.27	3.30	3.35	3.31	3.27
30	3.36	3.48	3.47	3.70	3.72	3.55
45	3.34	3.45	3.49	3.77	3.77	3.56
Mean	3.23	3.35	3.37	3.51	3.51	
CD at 5%	N=0.14		P=0.13		NxP=0.28	

NB : (i) A uniform dose of 30 kg K/ha was applied at the time of sowing

(ii) Seeds were soaked with 10^{-6}M GA_3 solution for 8 h before sowing and the plants grown from these seeds were sprayed with the same concentration of GA_3 at 40 DAS

4.3.4.1 Acid value

As mentioned above, the effect of N and P application, alone as well as in combination, was non-significant on this parameter (Table 47).

4.3.4.2 Iodine value

A reverse relationship between N doses and iodine value was noted, with N_{90} giving 8.9% lower iodine value than N_0.

A similar trend was noticed in the case of P application. Compared with P_0, treatment P_{30} decreased the iodine value by 8.9%.

The interaction (N x P) effect was non-significant on this parameter (Table 47).

4.3.4.3 Saponification value

The application of N_{90} gave the maximum saponification value, followed by N_{120}. Treatment N_{90} gave 2.8% higher value than N_0.

The treatment P_{30}, gave maximum value. However, the effect of P_{30} was followed by P_{45}, P_{15} and P_0 in that order. Treatment P_{30} increased saponification value by 2.1% in comparison with P_0.

The interaction (N x P) effect was non-significant on this parameter (Table 47).

4.4 Experiment 4

This simple randomized design experiment was performed to select the best dose of leaf-applied Ca for mustard (*Brassica juncea* L. Czern. & Coss.) variety Rohini grown with the best combination of soaking plus spray of GA_3 selected on the basis of the data of Experiment 2 coupled with those of basal N and P determined in Experiment 3. The parameters studied were

Table 47. Effect of basal N and P on acid, iodine and saponification value of mustard variety Rohini at harvest (Mean of four replicates)

P treatments (kg/ha)	N treatments (kg/ha)					Mean
	0	30	60	90	120	
			Acid value			
0	4.43	4.48	4.54	4.62	4.65	4.54
15	4.45	4.51	4.59	4.64	4.66	4.57
30	4.50	5.55	4.60	4.68	4.69	4.80
45	4.52	4.53	4.57	4.68	4.67	4.59
Mean	4.48	4.52	4.58	4.66	4.67	
CD at 5%	N = NS		P=NS		NxP=NS	
			Iodine value			
0	100.01	96.12	95.33	94.57	94.01	96.01
15	96.69	91.52	89.75	84.33	83.25	89.11
30	93.35	89.89	86.72	84.68	82.59	87.45
45	91.12	87.15	85.32	83.51	80.35	85.49
Mean	95.29	91.17	89.28	86.77	85.05	
CD at 5%	N=3.75		P=3.34		NxP=NS	
			Saponification value			
0	174.12	170.36	170.14	175.12	172.35	172.42
15	169.12	171.63	171.98	176.87	172.48	172.42
30	172.89	174.47	174.98	178.94	179.25	176.11
45	171.82	172.76	172.57	176.58	173.61	173.47
Mean	171.99	172.31	172.42	176.88	174.42	
CD at 5%	N=1.32		P=1.27		NxP=NS	

NB : (i) A uniform dose of 30 kg K/ha was applied at the time of sowing

(ii) Seeds were soaked with 10^{-6}M GA_3 solution for 8 h before sowing and the plants grown from these seeds were sprayed with the same concentration of GA_3 at 40 DAS

the same as in previous experiments. The results (Tables 48-56) are briefly described below.

4.4.1 Growth parameters

The effect of foliar application of Ca was significant on all growth parameters studied at 50 and 60 DAS (Table 48-49).

4.4.1.1 Shoot length per plant

At both stages, foliar application of Ca_1 proved best. Its effect was followed by that of Ca_2. Treatment Ca_1 increased shoot length per plant by 12.6 and 14.6% at 50 and 60 DAS respectively in comparison with the water-sprayed treatment, i.e. control (Table 48).

4.4.1.2 Leaf area per plant

At each stage, application of Ca_1 proved best for this parameter. Treatments Ca_2, Ca_0 and Ca_3, being at par, followed it at both stages. Treatment Ca_1 produced 10.3 and 10.2% more leaf area at 50 and 60 DAS respectively than the control (Table 48).

4.4.1.3 Fresh weight per plant

The application of Ca_1, followed by Ca_2, Ca_0 and Ca_3 in that order, gave maximum fresh weight at both stages. This treatment increased fresh matter by 12.6 and 14.4% at 50 and 60 DAS respectively compared with the control (Table 49).

4.4.1.4 Dry weight per plant

For dry weight per plant, the same trend was noted as for fresh weight per plant above at both stages. Treatment Ca_1 produced 10.7 and

Table 48. Effect of foliar application of Ca on shoot length per plant and leaf area per plant of mustard variety Rohini at two stages of growth (Mean of four replicates)

Foliar (F) treatments (kg Ca/ha)	Shoot length per plant (cm)		Leaf area per plant (cm^2)	
	50 DAS	60 DAS	50 DAS	60 DAS
0	51.0	54.2	525.8	549.2
1	57.4	62.1	579.7	605.2
2	53.0	56.0	531.0	555.7
3	48.2	51.4	494.3	518.5
CD at 5%	4.31	5.09	47.92	48.33

NB : (i) A uniform basal dose of $N_{90}P_{30}K_{30}$ was applied

(ii) Seeds were soaked with 10^{-6}M GA_3 solution for 8h before sowing and the plants grown from these seeds were sprayed with the same concentration of GA_3 solution containing Ca as per treatment at 40 DAS

Table 49. Effect of foliar application of Ca on fresh weight per plant and dry weight per plant of mustard variety Rohini at two stages of growth (Mean of four replicates)

Foliar (F) treatments (kg Ca/ha)	Fresh weight per plant (g)		Dry weight per plant (g)	
	50 DAS	60 DAS	50 DAS	60 DAS
0	8.74	9.82	3.00	3.34
1	9.84	11.23	3.32	3.67
2	8.95	10.15	3.03	3.39
3	8.28	10.29	2.82	3.15
CD at 5%	0.84	0.91	0.28	0.26

NB : (i) A uniform basal dose of $N_{90}P_{30}K_{30}$ was applied

(ii) Seeds were soaked with 10^{-6}M GA_3 solution for 8h before sowing and the plants grown from these seeds were sprayed with the same concentration of GA_3 solution containing Ca as per treatment at 40 DAS

9.9% more dry matter at 50 and 60 DAS respectively than the control (Table 49).

4.4.2 Physiological and bio-chemical parameters

The effect of foliar application of Ca was significant at both stages on all parameters studied, except leaf P and K content (Tables 50-53).

4.4.2.1 Net photosynthetic rate

At both stages, application of Ca_1 proved best. The effect of this treatment was followed by that of Ca_2 and Ca_0 at 50 DAS. However at 60 DAS, treatment Ca_2 showed parity with Ca_1 that gave 9.0 and 13.0% higher net photosynthetic rate at 50 and 60 DAS respectively than the control (Table 50).

4.4.2.2 Carbonic anhydrase activity

The treatment Ca_1, followed by Ca_2 and Ca_0, gave maximum enzyme activity at both stages. Spray of Ca_1 gave 10.3 and 14.3% higher enzyme activity at 50 and 60 DAS respectively than the control (Table 50).

4.4.2.3 Nitrate reductase activity

For the activity of this enzyme also, treatment Ca_1 gave the maximum value at both stages. Its effect was followed by that of Ca_2 and Ca_0 at each stage. Treatment Ca_1 gave 12.4 and 9.3% higher enzyme activity at 50 and 60 DAS respectively than the control (Table 51).

4.4.2.4 Leaf chlorophyll content

At each stage, application of Ca_1 proved best. However, the effect of this treatment was followed by that of Ca_2 and Ca_0 at 50 DAS and was at par with that of Ca_2 at 60 DAS. Treatment Ca_1 increased the leaf chlorophyll

Table 50. Effect of foliar application of Ca on net photosynthetic rate and carbonic anhydrase activity of mustard variety Rohini at two stages of growth (Mean of four replicates)

Foliar (F) treatments (kg Ca/ha)	Net photosynthetic rate [μ mol (CO_2)/m^2/s]		Carbonic anhydrase activity [mol (CO_2)/kg (f.m.)/s]	
	50 DAS	60 DAS	50 DAS	60 DAS
0	21.25	22.86	2.44	2.65
1	23.16	25.83	2.69	3.03
2	21.74	26.22	2.51	2.72
3	19.98	21.67	2.28	2.49
CD at 5%	1.27	1.35	0.16	0.17

NB : (i) A uniform basal dose of $N_{90}P_{30}K_{30}$ was applied

(ii) Seeds were soaked with 10^{-6}M GA_3 solution for 8h before sowing and the plants grown from these seeds were sprayed with the same concentration of GA_3 solution containing Ca as per treatment at 40 DAS

Table 51. Effect of foliar application of Ca on nitrate reductase activity and leaf chlorophyll content of mustard variety Rohini at two stages of growth (Mean of four replicates)

Foliar (F) treatments (kg Ca/ha)	Nitrate reductase activity [n mol (NO_2)/g(f.m.)/h]		Leaf chlorophyll content (g/kg)	
	50 DAS	60 DAS	50 DAS	60 DAS
0	383.28	425.53	1.981	2.148
1	430.81	465.10	2.221	2.338
2	396.31	437.45	2.038	2.375
3	363.15	397.87	1.848	2.043
CD at 5%	17.23	20.93	0.13	0.15

NB : (i) A uniform basal dose of $N_{90}P_{30}K_{30}$ was applied

(ii) Seeds were soaked with 10^{-6}M GA_3 solution for 8h before sowing and the plants grown from these seeds were sprayed with the same concentration of GA_3 solution containing Ca as per treatment at 40 DAS

content by 12.1 and 8.9% at 50 and 60 DAS respectively in comparison with the control (Table 51).

4.4.2.5 Leaf N content

At both stages, application of Ca_1 gave maximum value. However, the effect of this treatment was at par with that of Ca_2 and Ca_0 at each stage. Treatment Ca_1 increased the leaf N content by 6.3 and 6.3% at 50 and 60 DAS respectively over Ca_3 which gave the lowest value (Table 52).

4.4.2.6 Leaf P content

The effect of Ca application was non-significant on the P content in leaves at both stages (Table 52).

4.4.2.7 Leaf K content

Like leaf P content, the effect of Ca application was also non-significant on this parameter (Table 53).

4.4.2.8 Leaf Ca content

At both stages, treatment Ca_3 gave maximum value and its effect was at par with that of Ca_2. However, treatment Ca_1 that occupied the next position at each stage gave 10.4 and 14.8% higher leaf Ca content at 50 and 60 DAS respectively than the control (Table 53).

4.4.3 Yield parameters

The effect of leaf-applied Ca was found to be significant on all yield parameters except 1000-seed weight and oil content (Tables 54-55).

4.4.3.1 Pod number per plant

Of the Ca treatments, application of Ca_1 proved best. The remaining three treatments, being at par, proved less effective. Treatment Ca_1 gave 9.7% higher pod number per plant than the control (Table 54).

Table 52. Effect of foliar application of Ca on leaf N and P content of mustard variety Rohini at two stages of growth (Mean of four replicates)

Foliar (F) treatments (kg Ca/ha)	Leaf N content (%)		Leaf P content (%)	
	50 DAS	60 DAS	50 DAS	60 DAS
0	4.10	3.67	0.303	0.289
1	4.36	3.90	0.312	0.296
2	4.12	3.78	0.309	0.290
3	3.74	3.42	0.307	0.286
CD at 5%	0.35	0.39	NS	NS

NB : (i) A uniform basal dose of $N_{90}P_{30}K_{30}$ was applied

(ii) Seeds were soaked with 10^{-6}M GA_3 solution for 8h before sowing and the plants grown from these seeds were sprayed with the same concentration of GA_3 solution containing Ca as per treatment at 40 DAS

Table 53. Effect of foliar application of Ca on leaf K and Ca content of mustard variety Rohini at two stages of growth (Mean of four replicates)

Foliar (F) treatments (kg Ca/ha)	Leaf K content (%)		Leaf Ca content (%)	
	50 DAS	60 DAS	50 DAS	60 DAS
0	4.05	3.92	0.29	0.27
1	4.15	4.01	0.32	0.31
2	4.11	3.98	0.36	0.34
3	4.06	3.92	0.36	0.35
CD at 5%	NS	NS	0.02	0.02

NB : (i) A uniform basal dose of $N_{90}P_{30}K_{30}$ was applied

(ii) Seeds were soaked with 10^{-6}M GA_3 solution for 8h before sowing and the plants grown from these seeds were sprayed with the same concentration of GA_3 solution containing Ca as per treatment at 40 DAS

Table 54. Effect of foliar application of Ca on pod number per plant, seed number per pod and 1000-seed weight of mustard variety Rohini at harvest (Mean of four replicates)

Foliar (F) treatments (kg Ca/ha)	**Pod number per plant**	**Seed number per pod**	**1000-seed weight (g)**
0	141.75	12.00	3.97
1	155.50	13.00	4.26
2	143.00	11.00	4.30
3	133.75	10.75	4.21
CD at 5%	11.67	1.10	NS

NB : (i) A uniform basal dose of $N_{90}P_{30}K_{30}$ was applied

(ii) Seeds were soaked with 10^{-6}M GA_3 solution for 8h before sowing and the plants grown from these seeds were sprayed with the same concentration of GA_3 solution containing Ca as per treatment at 40 DAS

4.4.3.2 Seed number per pod

The spray treatment Ca_1 gave maximum value and its effect was followed by that of Ca_0, Ca_2 and Ca_3. Application of Ca_1 resulted in 8.3% higher seed number per pod compared with the control (Table 54).

4.4.3.3 1000-seed weight

The spray of Ca did not influence this parameter (Table 54).

4.4.3.4 Seed yield per plant

Application of foliar treatment Ca_1 proved best for this parameter. The effect of this treatment was followed by that of Ca_2, Ca_0 and Ca_3. Treatment Ca_1 increased seed yield by 11.9% in comparison with the control (Table 55).

4.4.3.5 Oil content

Foliar application of Ca did not affect this parameter significantly (Table 55).

4.4.3.6 Oil yield per plant

The spray of Ca_1 proved best. However, its effect was at par with that of Ca_2. Treatment Ca_1 increased oil yield per plant by 15.7% over the control (Table 55).

4.4.4 Quality parameters

The effect of foliar application of Ca was significant on saponification value only, other quality parameters not being affected (Table 56).

Table 55. Effect of foliar application of Ca on seed yield per plant, seed oil content, oil yield per plant of mustard variety Rohini at harvest (Mean of four replicates)

Foliar (F) treatments (kg Ca/ha)	**Seed yield per plant (g)**	**Oil content (%)**	**Oil yield per plant (g)**
0	10.32	36.85	3.82
1	11.55	38.19	4.42
2	10.43	39.06	4.06
3	9.65	37.23	3.59
CD at 5%	1.09	NS	0.32

NB : (i) A uniform basal dose of $N_{90}P_{30}K_{30}$ was applied

(ii) Seeds were soaked with 10^{-6}M GA_3 solution for 8h before sowing and the plants grown from these seeds were sprayed with the same concentration of GA_3 solution containing Ca as per treatment at 40 DAS

4.4.4.1 Acid value

Effect of leaf-applied Ca was non-significant on this parameter (Table 56), as indicated above.

4.4.4.2 Iodine value

The application of Ca spray was also found ineffective on this parameter (Table 56).

4.4.4.3 Saponification value

Foliar application of Ca_1 proved best. Its effect was followed by that of Ca_2. Treatment Ca_1 gave 3.2% higher value than the control (Table 56).

Table 56. Effect of foliar application of Ca on acid, iodine and saponification value of mustard variety Rohini at harvest (Mean of four replicates)

Foliar (F) treatments (kg Ca/ha)	**Acid value**	**Iodine value**	**Saponification value**
0	4.76	83.59	174.48
1	4.64	80.36	180.06
2	4.79	77.52	178.67
3	4.60	75.33	176.75
CD at 5%	NS	NS	1.28

NB : (i) A uniform basal dose of $N_{90}P_{30}K_{30}$ was applied

(ii) Seeds were soaked with 10^{-6}M GA_3 solution for 8h before sowing and the plants grown from these seeds were sprayed with the same concentration of GA_3 solution containing Ca as per treatment at 40 DAS

Discussion

CONTENTS

Chapter 5

DISCUSSION

Plants grow well in soil not only because it provides them anchorage but also essential nutrients for their growth and development. However, for sustained growth, plants require larger amounts of several nutrients than the quantity found in the soil at any given time under favourable conditions. Moreover, the requirement for the critical elements (N, P and K) is comparatively more than the other essential nutrients. Enhanced yields obtained through improved varieties of crops and intensive cultivation further increase the depletion of nutrients in arable land. Erosion, leaching, fixation, decomposition and volatilization, among other factors, cause additional nutrient losses.

Soil conditions, including availability of nutrients, could be ameliorated to a great extent by adopting better system of farming, soil management and manuring practices based on sound scientific foundation. In modern agriculture, judicious use of chemical fertilizers and other inputs has become an established practice to suit the actual requirements of a crop for exploiting its genetic potential fully (Patnaik, 2003) and to ensure good returns to the farmer through maximum productivity.

It has been reported that plant growth regulators, particularly IAA, GA_3 and Kn, play important roles in enhancing the productivity of crops (De-La-Guardia and Benlloch, 1980; Ray and Choudhuri, 1981; Bangal *et al.*, 1982; Erdei and Dhakal, 1988; Singh and Sahu, 1993; Agrawal *et al.*, 1994; Khan *et al.*, 1996, 2002; Khan and Samiullah, 2003; Azam, 2003).

Among these regulators, GA_3 is comparatively more effective than IAA which is followed by Kn (Khan *et al.*, 2002). The superiority of GA_3 has also been reported by Erdei and Dhakal (1988), Karmokar and Begum (1990), Gaikwad and Sundara (1993), Agrawal *et al.* (1994), Khan (1996), Khan *et al.*(1996) and Khan *et al.* (2002). In view of very low concentrations involved, it is logical to include GA_3 in innovative farm practices to test its role in improving the productivity of crops. However, as GA_3 induces elongation of shoot to the extent that it causes lodging resulting in some loss of yield, the application of nutrient(s) for providing mechanical strength to the crop could also be tested, particularly from the commercial angle.

Keeping these points in view, four pot experiments were performed under the agro-climatic conditions of Aligarh. Of these, Experiment 1 (exploratory varietal trial) and Experiment 4 were carried out according to a simple randomized and the remaining two (Experiments 2 and 3), by factorial randomized design. As mentioned earlier, the response of the crop to the treatments was assessed in terms of growth characteristics, physiological and bio-chemical markers and yield and quality parameters. The important results of the four experiments, discussed parameter-wise in the light of the findings of earlier workers, follow :

5.1 Growth parameters

It is evident from Tables 10 and 11 (Experiment 1) that the eighteen mustard varieties grown with a uniform (recommended) basal dose (90 kg N + 30 kg P + 30 kg K/ha) differed with each other in respect of growth parameters. In general, Pusa Bold, Pusa Jaikisan, Rohini and Varuna proved

better than the others at 50 and 60 DAS. For instance, Pusa Bold, Pusa Jaikisan, Rohini and Varuna produced the tallest plants and Suraj, the shortest at both stages. Maximum leaf area was noted in Pusa Bold, Pusa Jaikisan, Rohini and Varuna and minimum, in Suraj at each stage. Variety Pusa Jaikisan, Rohini and Varuna registered the highest and Suraj, the lowest value for fresh weight at both stages. Maximum dry weight was recorded in Pusa bold, Pusa Jaikisan, Rohini and Varuna at both stages (a notable exception being Pusa Bold at 60 DAS) and minimum, in Suraj.

The above findings regarding varietal variation in rapeseed-mustard corroborate the results of Vasi *et al.* (1986), Chaturvedi *et al.* (1988), Mohammad *et al.* (1989), Shukla and Kumar (1994), Tomer *et al.* (1996), Gurjar and Chauhan (1997), Mohammad and Khan (1997), Singh and Singh (2002) and Siddiqui and Mohammad (2004). The differences in growth behaviour of the varieties screened in Experiment 1 may be resulted from their specific genetic constitution.

The observed ameliorative effect of GA_3 application through seed and foliage over the water-treated control in Experiment 2 (Tables 18, 19) on shoot length and leaf area per plant at both stages of growth in the selected variety (Rohini) grown with the same basal dose of N, P and K as applied in Experiment 1 is in accordance with the results of earlier workers' including Saran *et al.* (1992), Khan (1996), Khan *et al.* (1996, 2002) and Khan and Samiullah (2003). This enhancing effect of GA_3 could be traced to its various roles in plants. For example, GA_3 treatment promotes, among others, cell division (Liu and Loy, 1976; Moore, 1989; Huttly and Phillips, 1995; Arteca, 1996), cell enlargement and differentiation (Huttly and

Phillips, 1995; Mobin, 1999; Buchanan *et al.* 2000; Marschner, 2002), chlorophyll content (Afroz *et al.*, 2005), deoxyribose nucleic acid, ribose nucleic acid and protein synthesis (Broughton, 1968; Johri and Varner, 1968; Roth Benjerano and Lips, 1970; Pain and Dutta, 1977; Mozer, 1980), synthesis of other enzymes, especially hydrolases, (Marschner, 2002), membrane permeability (Wood and Pleg, 1972, 1974; Crozier and Turnbull, 1984), metabolism of storage products (Mobin, 1999), net photosynthetic rate (Afroz *et al.*, 2005), ribose and polyribose multiplication (Evans and Varner, 1972), synthesis of new materials (Mobin, 1999) and transport of photosynthates (Mulligan and Patrick, 1979; Aloni *et al.*, 1986; Dae *et al.*, 1986; Estruch *et al.*, 1989; Hayat *et al.*, 2001) that could lead to the observed enhancement in plant height and leaf area.

The spectacular increase over the no nutrient control (N_0P_0) in values for shoot length and leaf area per plant at both stages in the case of variety Rohini due to the application of N and P (with uniform K) to plants grown with a uniform treatment of GA_3 in Experiment 3 (Tables 33-34) is a welcome observation. These results broadly corroborate the findings of Saran and Giri (1990), Joshi *et al.* (1991), Khan *et al.* (1996), Tomer *et al.* (1996, 1997) and Mohammad (2004). The beneficial effect of N and P application in soil could be ascribed to the well known fact that continuous cropping depletes the soil of nutrients, particularly N, P (and K), due to the heavy demand of crops, specially of their high yielding varieties. Exogenous application of these nutrients would expectedly benefit the growing crops when N and their availability became inadequate at later stage of growth.

As far as its roles are concerned, N is a component of a number of metabolites, including amino acids, chlorophyll, coenzymes, enzymes, proteins, purines and pyrimidines. Similarly, P is an integral part of many compounds, including co-enzymes, nucleic acids, nucleotides, phospholipids, phosphoric acid, phosphorylated sugars and sugar phospholipids (Marschner, 2002). It may be added that the relatively high amounts of K are required by plants for normal growth, but this situation does not correlate with the observed functions of K as it does not enter into the composition of any organic compound in the plant. None the less, the functions mostly as catalytic agent in several enzymatic reactions. Its probable role is to provide the necessary ionic environment for preserving the proper three dimensional structure of enzymes for optimal activity (Evans and Sorger, 1966). In addition, it is essential for translocation of sugars, opening and closing of stomata and osmoregulation (Marschner, 2002; Mukherji and Ghosh, 2005). Keeping the roles of these three nutrients (N, P and K) in view, it could be added that they are involved directly or indirectly in cell division, cell enlargement and tissue and organ development. Thus, an improvement in these structures would result in increase in the growth parameters. Moreover, enhanced plant height would ensure better orientation of leaves to harvest maximum solar energy leading to larger leaf area of the nutrient treated plants.

The enhancing effect of leaf-applied Ca at both stages over the water-sprayed control on plant height and leaf area of variety Rohini grown with a uniform dose of GA_3 and selected nutrients in Experiment 4 is noteworthy observation (Table 48). An increase in leaf area due to Ca

application was also observed by Shanker *et al.* (2001). The beneficial effect of Ca on these growth parameters can be ascribed to its various roles in plants. For example, Wyn Jones and Lunt (1967); Berridge *et al.* (1998); Marschner (2002); Mukherji and Ghosh (2005) noted that :

(i) it acts as a second messenger and an activator of many enzymes, including adenosine triphosphatase, adenyl kinase, alpha amylase, arginine kinase, phospholipase and potatoapyrase,

(ii) it aids in neutralizing acids, especially oxalic acid which might limit growth,

(iii) it enters the cell wall and forms calciumpectate,

(iv) it helps in figuration of growing tips of roots and shoots,

(v) it is involved in mitochondria and plasma membrane formation, mitotic cell division and cell elongation,

(vi) it regulates the activity of chloroplasts, and

(vii) it stimulates absorption of ammonium, K and P, development of root hairs, movement and utilization of carbohydrates and amino acids and the process of photosynthesis.

Thus, Ca may take part directly or indirectly in the development of shoot length and leaf area; hence the observed enhancement in the values of these attributes.

Improvement in shoot length and leaf area (Tables 18, 19, 33, 34 and 48) was expectedly reflected in increased fresh and dry weight (Tables 20, 21, 35, 36, 49) of the treated plants. This proposition is further

confirmed by correlation studies as these two parameters were found to be significantly and positively correlated with fresh and dry matter accumulation (Tables 57-59). Similar increase in dry matter production due to application of GA_3 has also been reported by other workers (Saran *et al.*, 1992; Khan, 1996; Khan *et al.*, 1996, 2000; Khan and Samiullah, 2003), NPK nutrients (Saran and Giri, 1990; Tomer *et al.*, 1996, 1997; Mohammad, 2004) and Ca (Sharma and Kamath, 1990; Khan *et al.*, 2001; Shanker *et al.*, 2001).

5.2 Physiological and bio-chemical parameters

The general superiority of Pusa Bold, Pusa Jaikisan, Rohini and Varuna in respect of net photosynthetic rate, carbonic anhydrase and nitrate reductase activity, leaf chlorophyll and leaf N, P and K content at one or the other stage of growth in Experiment 1 (Tables 12-14) may be ascribed to their superior genetic make-up. Similar variations have also been reported by Siddiqui and Mohammad (2004).

The enhancement in net photosynthetic rate, carbonic anhydrase activity, nitrate reductase activity and chlorophyll content over the water-treated control resulting from treatment with GA_3 noted in Experiment 2 (Tables 22-25) is a noteworthy observation. These results are also in accordance with the findings of Sharma *et al.* (1980), Saran *et al.* (1992), Khan (1996), Hayat *et al.* (2001), Khan and Samiullah (2003) and Afroz *et al.* (2005). The increase in carbonic anhydrase activity due to GA_3 application may be ascribed to increase in transcription and/or translation of the gene in treated plants that code for carbonic anhydrase (Okabe *et al.*, 1980; 1984; Sugiharto *et al.*, 1992). Increased nitrate reductase activity may

Table 57. Correlation coefficient(r) values for different pairs of characteristics of mustard in Experiment 2.

Characteristics	Sampling stages (DAS)	Shoot length per plant		Leaf area per plant		Fresh weight per plant		Dry weight per plant	
		Sampling stages (DAS)		Sampling stages (DAS)		Sampling stage (DAS)		Sampling stages (DAS)	
		50	60	50	60	50	60	50	60
Shoot length per plant	50			0.967		0.970		0.968	
	60				0.967		0.981		0.959
Leaf area per plant	50					0.955		0.980	
	60						0.973		0.989
Fresh weight per plant	50							0.984	
	60								0.974
Dry weight per plant	50								
	60								
Net photosynthetic rate	50								
	60								
Carbonic anhydrase activity	50								
	60								
Nitrate reductase activity	50								
	60								
Leaf chlorophyll content	50								
	60								

Significant at 5% r value 0.497

Contd...

Table 57 (Contd.). Correlation coefficient(r) values for different pairs of characteristics of mustard in Experiment 2.

Characteristics	Sampling stages (DAS)	Net photosynthetic rate		Carbonic anhydrase activity		Nitrate reductase activity		Leaf chlorophyll content	
		Sampling stages (DAS)		Sampling stages (DAS)		Sampling stage (DAS)		Sampling stages (DAS)	
		50	60	50	60	50	60	50	60
Shoot length per plant	50	0.977	--	0.991	--	0.985	--	0.993	
	60	--	0.984	--	0.971		0.979		0.984
Leaf area per plant	50	0.975	--	0.973	--	0.967	--	0.984	--
	60	--	0.969	--	0.968	--	0.945	--	0.962
Fresh weight per plant	50	0.980	--	0.970	--	0.975	--	0.974	
	60	--	0.998	--	0.992	--	0.989	--	0.982
Dry weight per plant	50	0.981	--	0.974	--	0.975		0.983	
	60	--	0.973	--	0.972	--	0.940	--	0.956
Net photosynthetic rate	50	--	--	0.991	--	0.986	--	0.985	--
	60	--	--	--	0.990	--	0.989	--	0.983
Carbonic anhydrase activity	50	--	--	--	--	0.990	--	0.992	--
	60		--	--			0.975		0.982
Nitrate reductase activity	50	--	--	--	--	--	--	0.986	--
	60	--	--	--	--	--	--	--	0.976
Leaf chlorophyll content	50	--	--	--					
	60	--	--	--				--	
Significant at 5%	r value 0.497								Contd...

Table 57 (Contd.). Correlation coefficient(r) values for different pairs of characteristics of mustard in Experiment 2.

Characteristics	Sampling stages (DAS)	Leaf N content		Leaf P content		Leaf K content		Pod number per plant
		Sampling stages (DAS)		Sampling stages (DAS)		Sampling stage (DAS)		
		50	60	50	60	50	60	
Shoot length per plant	50	0.982	—	0.507	—	0.794	—	0.960
	60	—	0.975	—	-0.094	—	0.872	0.948
Leaf area per plant	50	0.972	—	0.501	—	0.724	—	0.967
	60	—	0.979	—	0.009	—	0.821	0.974
Fresh weight per plant	50	0.975	—	0.471	—	0.735	—	0.950
	60	—	0.994	—	-0.019	—	0.900	0.969
Dry weight per plant	50	0.982	—	0.543	—	0.676	—	0.980
	60	—	0.986	—	0.001	—	0.809	0.985
Net photosynthetic rate	50	0.985	—	0.433	—	0.755	—	0.974
	60	—	0.992	—	-0.048	—	0.898	0.968
Carbonic anhydrase activity	50	0.990	—	0.465	—	0.769	—	0.972
	60	—	0.984	—	-0.077	—	0.912	0.972
Nitrate reductase activity	50	0.996	—	0.489	—	0.766	—	0.963
	60	—	0.978	—	-0.044	—	0.914	0.942
Leaf chlorophyll content	50	0.987	—	0.516	—	0.757	—	0.974
	60	—	0.971	—	-0.112	—	0.916	0.961
Significant at 5%	r value 0.497							Contd...

Table 57 (Contd.). Correlation coefficient(r) values for different pairs of characteristics of mustard in Experiment 2.

Characteristics	Sampling stages (DAS)	Seed number per pod	1000-seed weight	Seed yield per plant	Oil Content
Shoot length per plant	50	-0.088	0.507	0.964	0.219
	60	0.023	0.534	0.964	0.279
Leaf area per plant	50	-0.077	0.467	0.977	0.299
	60	0.030	0.402	0.985	0.362
Fresh weight per plant	50	0.057	0.487	0.968	0.293
	60	-0.077	0.508	0.984	0.309
Dry weight per plant	50	0.038	0.443	0.986	0.347
	60	-0.016	0.413	0.994	0.320
Net photosynthetic rate	50	-0.056	0.467	0.988	0.273
	60	-0.075	0.502	0.984	0.285
Carbonic anhydrase activity	50	-0.092	0.507	0.978	0.268
	60	-0.092	0.498	0.980	0.274
Nitrate reductase activity	50	-0.073	0.543	0.979	0.301
	60	-0.091	0.580	0.960	0.320
Leaf chlorophyll content	50	-0.081	0.487	0.979	0.239
	60	-0.077	0.508	0.963	0.226
Significant at 5%	r value 0.497				Contd...

Table 57 (Contd.). Correlation coefficient(r) values for different pairs of characteristics of mustard in Experiment 2.

Characteristics	Sampling stages (DAS)	Oil yield per plant	Acid value	Iodine value	Saponification value
Shoot length per plant	50	0.835	0.810	0.629	0.126
	60	0.861	0.775	0.668	0.221
Leaf area per plant	50	0.878	0.817	0.678	0.112
	60	0.912	0.827	0.727	0.096
Fresh weight per plant	50	0.870	0.791	0.681	0.190
	60	0.890	0.840	0.682	0.098
Dry weight per plant	50	0.908	0.815	0.733	0.127
	60	0.902	0.834	0.732	0.083
Net photosynthetic rate	50	0.876	0.853	0.686	0.112
	60	0.880	0.842	0.684	0.099
Carbonic anhydrase activity	50	0.867	0.830	0.664	0.107
	60	0.871	0.855	0.669	0.104
Nitrate reductase activity	50	0.883	0.822	0.666	0.143
	60	0.876	0.812	0.650	0.147
Leaf chlorophyll content	50	0.855	0.817	0.652	0.125
	60	0.837	0.807	0.634	0.148
Significant at 5%	r value 0.497				Contd...

Table 57 (Contd.). Correlation coefficient(r) values for different pairs of characteristics of mustard in Experiment 2.

Characteristics	Sampling stages (DAS)	Leaf N content		Leaf P content		Leaf K content		Pod number per plant
		Sampling stages (DAS)		Sampling stages (DAS)		Sampling stage (DAS)		
		50	60	50	60	50	60	
Leaf N content	50	--	--	0.502		0.740		0.971
	60	--	--	--	-0.006	-	0.863	0.976
Leaf P content	50					0.145		0.501
	60	--	--	--	--	--	-0.223	0.023
Leaf K content	50	--	--	--	--	--	--	0.657
	60	-	--	--	--	--		0.832
Pod number per plant		--	--	--	--	--		
Seed number per pod		--	--	--	--	--	--	--
1000-seed weight		--	--	--	--	--	--	--
Seed yield per plant		--						
Oil content		—	—	--	--	--	--	--
Oil yield per plant								
Acid value			--			--		--
Iodine value		-	--	--			-	
Saponification value								

Significant at 5% r value 0.497

Contd...

Table 57 (Contd.). Correlation coefficient(r) values for different pairs of characteristics of mustard in Experiment 2.

Characteristics	Sampling stages (DAS)	Seed number per pod	1000-seed weight	Seed yield per plant	Oil content
Leaf N content	50	-0.086	0.521	0.984	0.327
	60	-0.078	0.516	0.992	0.327
Leaf P content	50	0.296	-0.020	0.492	0.239
	60	0.120	-0.233	-0.007	0.724
Leaf K content	50	-0.358	0.488	0.669	-0.114
	60	-0.295	0.496	0.836	0.059
Pod number per plant		-0.045	0.406	0.987	0.330
Seed number per pod		--	-0.160	-0.034	0.319
1000-seed weight		--	--	0.447	0.195
Seed yield per plant		--	--	--	0.331
Oil content		--	--	--	--
Oil yield per plant		--	--	--	--
Acid value		--	--	--	--
Iodine value		--	--	--	--
Saponification value		--	--	--	--
Significant at 5%	r value 0.497				Contd...

Table 57 (Contd.). Correlation coefficient(r) values for different pairs of characteristics of mustard in Experiment 2.

Characteristics	Sampling stages (DAS)	Oil yield per plant	Acid value	Iodine value	Saponification value
Leaf N content	50	0.898	0.836	0.685	0.098
	60	0.904	0.836	0.686	0.119
Leaf P content	50	0.489	0.348	0.614	-0.142
	60	0.317	0.130	0.379	-0.483
Leaf K content	50	0.456	0.635	0.157	0.161
	60	0.663	0.778	0.406	0.064
Pod number per plant		0.902	0.851	0.731	0.057
Seed number per pod		0.117	-0.289	0.403	0.354
1000-seed weight		0.429	0.199	0.114	0.664
Seed yield per plant		0.911	0.850	0.744	0.079
Oil content		0.689	0.311	0.637	-0.065
Oil yield per plant			0.788	0.851	0.033
Acid value				0.635	-0.302
Iodine value					-0.125
Saponification value					

Significant at 5% r value 0.497

Table 58. Correlation coefficient (r) values for different pairs of characteristics of mustard in Experiment 3

Characteristics	Sampling stages (DAS)	Shoot length per plant		Leaf area per plant		Fresh weight per plant		Dry weight per plant	
		Sampling stages (DAS)		Sampling stages (DAS)		Sampling stage (DAS)		Sampling stages (DAS)	
		50	60	50	60	50	60	50	60
Shoot length per plant	50			0.915		0.950		0.932	
	60				0.914		0.987		0.990
Leaf area per plant	50	--	--	—	--	0.986	--	0.985	--
	60	—	—	—	--	—	0.915	--	0.951
Fresh weight per plant	50	--	--	--	--	--	--	0.983	
	60	—	--	--	--	--	--	—	0.984
Dry weight per plant	50	--	--	--	--	--	--	--	--
	60	—	—	--	--	—	--	--	--
Net photosynthetic rate	50	—	—	—	--	—	--	--	--
	60	—	--	--	--	—	--	--	--
Carbonic anhydrase activity	50	--	—	—	--	--	--	--	--
	60	--	--	--	--	--	--	--	--
Nitrate reductase activity	50	--	--	--	--	--	--	--	--
	60	--	--	--	--	--	--	--	--
Leaf chlorophyll content	50	—	--	--	--	--	--	--	--
	60								

Significant at 5% r value 0.444

Contd...

Table 58 (Contd.). Correlation coefficient(r) values for different pairs of characteristics of mustard in Experiment 3.

Characteristics	Sampling stages (DAS)	Net photosynthetic rate		Carbonic anhydrase activity		Nitrate reductase activity		Leaf chlorophyll content	
		Sampling stages (DAS)		Sampling stages (DAS)		Sampling stage (DAS)		Sampling stages (DAS)	
		50	60	50	60	50	60	50	60
Shoot length per plant	50	0.971		0.983		0.981		0.985	
	60		0.992		0.958		0.959		0.994
Leaf area per plant	50	0.952		0.934		0.945		0.952	
	60		0.911		0.786		0.870		0.945
Fresh weight per plant	50	0.976		0.954		0.975		0.976	
	60		0.970		0.950		0.965		0.986
Dry weight per plant	50	0.973		0.940		0.957		0.964	
	60		0.986		0.924		0.954		0.997
Net photosynthetic rate	50			0.971		0.987		0.984	
	60				0.954		0.954		0.987
Carbonic anhydrase activity	50					0.980		0.986	
	60						0.932		0.933
Nitrate reductase activity	50							0.983	
	60								0.960
Leaf chlorophyll content	50								
	60								

Significant at 5% r value 0.444

Contd...

Table 58 (Contd.). Correlation coefficient(r) values for different pairs of characteristics of mustard in Experiment 3.

Characteristics	Sampling stages (DAS)	Leaf N content		Leaf P content		Leaf K content		Pod number per plant
		Sampling stages (DAS)		Sampling stages (DAS)		Sampling stage (DAS)		
		50	60	50	60	50	60	
Shoot length per plant	50	0.957		-0.287		-0.399		0.918
	60		0.706		0.089		0.129	0.967
Leaf area per plant	50	0.951		-0.102		-0.263		0.989
	60		0.491		0.238		0.291	0.980
Fresh weight per plant	50	0.965		-0.122		-0.272		0.980
	60		0.641		0.144		0.160	0.966
Dry weight per plant	50	0.970		-0.098		-0.253		0.996
	60		0.661		0.119		0.156	0.989
Net photosynthetic rate	50	0.979		-0.218		-0.362		0.960
	60		0.741		0.017		0.067	0.962
Carbonic anhydrase activity	50	0.943		-0.216		-0.348		0.928
	60		0.774		-0.023		-0.013	0.875
Nitrate reductase activity	50	0.962		-0.236		-0.331		0.946
	60		0.611		0.016		-0.008	0.931
Leaf chlorophyll content	50	0.968		-0.195		-0.354		0.952
	60		0.657		0.111		0.151	0.983
Significant at 5%	r value 0.444							

Contd...

Table 58 (Contd.). Correlation coefficient(r) values for different pairs of characteristics of mustard in Experiment 3.

Characteristics	Sampling stages (DAS)	Seed number per pod	1000-seed weight	Seed yield per plant	Oil Content
Shoot length per plant	50	0.907	0.924	0.971	-0.022
	60	0.874	0.891	0.994	0.061
Leaf area per plant	50	0.815	0.815	0.956	0.122
	60	0.745	0.736	0.920	0.157
Fresh weight per plant	50	0.827	0.838	0.979	0.120
	60	0.848	0.863	0.982	0.109
Dry weight per plant	50	0.840	0.844	0.979	0.120
	60	0.868	0.875	0.988	0.082
Net photosynthetic rate	50	0.864	0.881	0.997	0.022
	60	0.895	0.906	0.988	-0.007
Carbonic anhydrase activity	50	0.876	0.897	0.964	0.052
	60	0.868	0.897	0.947	-0.013
Nitrate reductase activity	50	0.873	0.890	0.986	0.027
	60	0.884	0.887	0.972	-0.053
Leaf chlorophyll content	50	0.890	0.909	0.982	0.057
	60	0.861	0.873	0.995	0.067
Significant at 5%	r value 0.444				Contd...

Table 58 (Contd.). Correlation coefficient(r) values for different pairs of characteristics of mustard in Experiment 3.

Characteristics	Sampling stages (DAS)	Oil yield per plant	Acid value	Iodine value	Saponification value
Shoot length per plant	50	0.844	0.260	-0.863	0.604
	60	0.903	0.247	-0.853	0.616
Leaf area per plant	50	0.898	0.157	-0.772	0.600
	60	0.883	0.170	-0.674	0.588
Fresh weight per plant	50	0.918	0.245	-0.815	0.635
	60	0.914	0.200	-0.846	0.586
Dry weight per plant	50	0.917	0.190	-0.795	0.586
	60	0.907	0.195	-0.820	0.596
Net photosynthetic rate	50	0.889	0.238	-0.834	0.569
	60	0.867	0.254	-0.820	0.619
Carbonic anhydrase activity	50	0.872	0.240	-0.902	0.586
	60	0.827	0.303	-0.881	0.604
Nitrate reductase activity	50	0.880	0.280	-0.849	0.623
	60	0.834	0.213	-0.746	0.533
Leaf chlorophyll content	50	0.890	0.214	-0.881	0.586
	60	0.907	0.220	-0.824	0.584
Significant at 5%	r value 0.444				Contd...

Table 58 (Contd.). Correlation coefficient(r) values for different pairs of characteristics of mustard in Experiment 3.

Characteristics	Sampling stages (DAS)	Leaf N content		Leaf P content		Leaf K content		Pod number per plant
		Sampling stages (DAS)		Sampling stages (DAS)		Sampling stage (DAS)		
		50	60	50	60	50	60	
Leaf N content	50	—	—	-0.212		-0.380		0.962
	60	—	—	—	-0.352	—	-0.267	0.585
Leaf P content	50	—	—	—	—	0.759	—	-0.085
	60	—	—	—	—	—	0.918	0.193
Leaf K content	50	—	—	—	—	—	—	-0.246
	60	—	—	—	—	—	—	0.228
Pod number per plant		—	—	—	—	—	—	—
Seed number per pod		—	—	—	—	—	—	—
1000-seed weight		—	—	—	—	—	—	—
Seed yield per plant		—	—	—	—	—	—	—
Oil content		—	—	—	—	—	—	—
Oil yield per plant		—	—	—	—	—	—	—
Acid value		—	—	—	—	—	—	—
Iodine value		—	—	—	—	—	—	—
Saponification value								

Significant at 5% r value 0.444

Contd...

Table 58 (Contd.). Correlation coefficient(r) values for different pairs of characteristics of mustard in Experiment 3.

Characteristics	Sampling stages (DAS)	Seed number per pod	1000-seed weight	Seed yield per plant	Oil content
Leaf N content	50	0.881	0.886	0.985	-0.021
	60	0.775	0.797	0.668	-0.262
Leaf P content	50	-0.474	-0.451	-0.208	0.913
	60	-0.251	-0.231	0.072	0.943
Leaf K content	50	-0.520	-0.514	-0.336	0.715
	60	-0.210	-0.187	0.111	0.906
Pod number per plant		0.838	0.837	0.967	0.136
Seed number per pod		—	0.993	0.869	-0.256
1000-seed weight		—	—	0.881	-0.224
Seed yield per plant		—	—	—	0.028
Oil content		—	—	—	—
Oil yield per plant					
Acid value		—	—	—	—
Iodine value		—	—	—	
Saponification value					
Significant at 5%	r value 0.444				

Contd...

Table 58 (Contd.). Correlation coefficient(r) values for different pairs of characteristics of mustard in Experiment 3.

Characteristics	Sampling stages (DAS)	Oil yield per plant	Acid value	Iodine value	Saponification value
Leaf N content	50	0.860	0.204	-0.762	0.572
	60	0.465	0.202	-0.713	0.504
Leaf P content	50	0.229	0.091	-0.022	-0.048
	60	0.488	0.170	-0.237	0.182
Leaf K content	50	0.023	0.069	0.132	0.041
	60	0.507	0.137	-0.281	0.208
Pod number per plant		0.914	0.218	-0.770	0.625
Seed number per pod		0.648	0.178	-0.703	0.538
1000-seed weight		0.674	0.209	-0.754	0.537
Seed yield per plant		0.894	0.244	-0.821	0.598
Oil content		0.473	0.242	-0.307	0.211
Oil yield per plant		--	0.323	-0.859	0.617
Acid value		--	--	-0.261	0.623
Iodine value		--	--	--	-0.509
Saponification value		--	--		
Significant at 5%	r value 0.444				

Table 59. Correlation coefficient(r) values for different pairs of characteristics of mustard in Experiment 4.

Characteristics	Sampling stages (DAS)	Shoot length per plant		Leaf area per plant		Fresh weight per plant		Dry weight per plant	
		Sampling stages (DAS)		Sampling stages (DAS)		Sampling stage (DAS)		Sampling stages (DAS)	
		50	60	50	60	50	60	50	60
Shoot length per plant	50			0.998		0.994		0.988	
	60				0.994		0.804		0.994
Leaf area per plant	50					0.996		1.000	
	60						0.754		0.999
Fresh weight per plant	50							0.997	
	60								0.738
Dry weight per plant	50								
	60								
Net photosynthetic rate	50								
	60								
Carbonic anhydrase activity	50								
	60								
Nitrate reductase activity	50								
	60								
Leaf chlorophyll content	50								
	60								

Significant at 5% r value 0.950

Contd...

Table 59 (Contd.). Correlation coefficient(r) values for different pairs of characteristics of mustard in Experiment 4.

Characteristics	Sampling stages (DAS)	Net photosynthetic rate		Carbonic anhydrase activity		Nitrate reductase activity		Leaf chlorophyll content	
		Sampling stages (DAS)		Sampling stages (DAS)		Sampling stage (DAS)		Sampling stages (DAS)	
		50	60	50	60	50	60	50	60
Shoot length per plant	50	0.994		0.995		0.999		0.998	
	60		0.791		0.999		0.978		0.778
Leaf area per plant	50	0.990		0.988		0.992		0.995	
	60		0.765		0.998		0.984		0.758
Fresh weight per plant	50	0.987		0.987		0.998		0.995	
	60		0.469		0.787		0.664		0.424
Dry weight per plant	50	0.988		0.987		0.992		0.994	
	60		0.786		0.997		0.990		0.781
Net photosynthetic rate	50			1.00		0.993		0.998	
	60				0.780		0.857		0.998
Carbonic anhydrase activity	50					0.994		0.998	
	60						0.981		0.769
Nitrate reductase activity	50							0.998	
	60								0.856
Leaf chlorophyll content	50								
	60								

Significant at 5% r value 0.950

Contd...

Table 59 (Contd.). Correlation coefficient(r) values for different pairs of characteristics of mustard in Experiment 4.

Characteristics	Sampling stages (DAS)	Leaf N content		Leaf P content		Leaf K content		Leaf Ca content	
		Sampling stages (DAS)		Sampling stages (DAS)		Sampling stage (DAS)		Sampling stage (DAS)	
		50	60	50	60	50	60	50	60
Shoot length per plant	50	0.951	--	0.726		0.916		-0.258	
	60	--	0.921	--	0.997	--	0.916	--	-0.225
Leaf area per plant	50	0.961	--	0.649		0.857		-0.388	
	60	--	0.933	--	0.998	--	0.874		-0.329
Fresh weight per plant	50	0.942	--	0.713	--	0.898	--	-0.309	
	60	--	0.521	--	0.792	--	0.782	--	0.186
Dry weight per plant	50	0.958	--	0.654	--	0.859	--	-0.385	
	60	--	0.946	--	0.996	--	0.881	--	-0.325
Net photosynthetic rate	50	0.979	--	0.651	--	0.872	--	-0.338	--
	60	--	0.902	--	0.759	--	0.917	--	0.061
Carbonic anhydrase activity	50	0.976	--	0.660	--	0.879	--	-0.323	--
	60	--	0.925	--	0.999	--	0.900	--	-0.265
Nitrate reductase activity	50	0.948	--	0.725		0.913	--	-0.272	
	60		0.982		0.975		0.899		-0.309
Leaf chlorophyll content	50	0.967	--	0.680		0.887		-0.332	
	60	--	0.910	--	0.748	--	0.895		0.016
Significant at 5%	r value 0.950								Contd...

Table 59 (Contd.). Correlation coefficient(r) values for different pairs of characteristics of mustard in Experiment 4.

Characteristics	Sampling stages (DAS)	Pod number per plant	Seed number per pod	1000-seed weight	Seed yield per plant	Oil Content
Shoot length per plant	50	0.987	0.857	0.372	0.987	0.539
	60	0.991	0.893	0.363	0.993	0.479
Leaf area per plant	50	1.000	0.923	0.246	1.00	0.405
	60	1.00	0.920	0.262	1.00	0.415
Fresh weight per plant	50	0.995	0.904	0.328	0.997	0.457
	60	0.743	0.741	0.579	0.760	0.333
Dry weight per plant	50	1.00	0.925	0.250	1.00	0.401
	60	0.999	0.907	0.270	0.998	0.439
Net photosynthetic rate	50	0.989	0.863	0.288	0.987	0.505
	60	0.755	0.452	0.585	0.751	0.878
Carbonic anhydrase activity	50	0.987	0.856	0.302	0.985	0.518
	60	0.996	0.906	0.324	0.997	0.452
Nitrate reductase activity	50	0.991	0.873	0.361	0.991	0.514
	60	0.982	0.843	0.295	0.979	0.529
Leaf chlorophyll content	50	0.994	0.879	0.309	0.993	0.493
	60	0.750	0.445	0.540	0.744	0.864
Significant at 5%	r value 0.950					Contd...

Table 59 (Contd.). Correlation coefficient(r) values for different pairs of characteristics of mustard in Experiment 4.

Characteristics	Sampling stages (DAS)	Oil yield per plant	Acid value	Iodine value	Saponification value
Shoot length per plant	50	0.973	0.085	0.359	0.742
	60	0.949	-0.012	0.349	0.744
Leaf area per plant	50	0.928	0.047	0.464	0.655
	60	0.932	0.038	0.448	0.668
Fresh weight per plant	50	0.944	0.006	0.385	0.718
	60	0.682	-0.579	-0.114	0.834
Dry weight per plant	50	0.926	0.034	0.458	0.659
	60	0.942	0.071	0.448	0.671
Net photosynthetic rate	50	0.964	0.164	0.447	0.673
	60	0.943	0.417	0.101	0.770
Carbonic anhydrase activity	50	0.968	0.164	0.434	0.683
	60	0.942	0.004	0.388	0.715
Nitrate reductase activity	50	0.965	0.056	0.364	0.738
	60	0.969	0.199	0.444	0.672
Leaf chlorophyll content	50	0.961	0.104	0.420	0.696
	60	0.935	0.469	0.145	0.729
Significant at 5%	r value 0.950				Contd...

Table 59 (Contd.). Correlation coefficient(r) values for different pairs of characteristics of mustard in Experiment 4.

Characteristics	Sampling stages (DAS)	Leaf N content		Leaf P content		Leaf K content		Leaf Ca content	
		Sampling stages (DAS)		Sampling stages (DAS)		Sampling stage (DAS)		Sampling stage (DAS)	
		50	60	50	60	50	60	50	60
Leaf N content	50	--	--	0.484		0.758	--	-0.483	
	60	--	--	--	0.916	--	0.866	--	-0.335
Leaf P content	50	--	--	--		0.936		0.422	
	60	--	--	--	--	--	0.888		-0.282
Leaf K content	50	--	--	--	--	--	--	0.142	
	60	--	--	--	--	--	--		0.139
Leaf Ca content	50	--	--	--	--	--	--	--	--
	60	--	--	--	--	--	--	--	--
Pod number per plant		--	--	--	--	--	--	--	--
Seed number per pod		--	--	--	--	--	--	--	--
1000-seed weight		--	--	--	--	--	--	--	--
Seed yield per plant		--	--	--	--	--	--	--	--
Oil content		--	--	--					
Oil yield per plant		--	--	--	--	--	--	--	--
Acid value		--	--	--	--	--	--	--	--
Iodine value		--	--	--					
Saponification value		--	--	--		--	--	--	--

Significant at 5% r value 0.950

Contd...

Table 59 (Contd.). Correlation coefficient(r) values for different pairs of characteristics of mustard in Experiment 4.

Characteristics	Sampling stages (DAS)	Pod number per plant	Seed number per pod	1000-seed weight	Seed yield per plant	Oil content
Leaf N content	50	0.962	0.847	0.113	0.955	0.420
	60	0.993	0.750	0.261	0.926	0.587
Leaf P content	50	0.643	0.471	0.874	0.658	0.718
	60	0.996	0.919	0.303	0.998	0.424
Leaf K content	50	0.853	0.663	0.710	0.861	0.733
	60	0.862	0.645	0.683	0.867	0.776
Leaf Ca content	50	-0.397	-0.596	0.798	-0.383	0.552
	60	-0.353	-0.515	0.818	-0.336	0.499
Pod number per plant		--	0.926	0.237	1.00	0.396
Seed number per pod		--	--	-0.014	0.928	0.033
1000-seed weight		--	--	--	0.252	0.828
Seed yield per plant		--	--	--	--	0.397
Oil content		--	--	--	--	--
Oil yield per plant						
Acid value		--	--	--		--
Iodine value		--	--	--		--
Saponification value		--	--			

Significant at 5% r value 0.950

Contd...

Table 59 (Contd.). Correlation coefficient(r) values for different pairs of characteristics of mustard in Experiment 4.

Characteristics	Sampling stages (DAS)	Oil yield per plant	Acid value	Iodine value	Saponification value
Leaf N content	50	0.914	0.313	0.605	0.516
	60	0.961	0.379	0.478	0.609
Leaf P content	50	0.768	-0.339	-0.373	0.994
	60	0.931	-0.015	0.401	0.702
Leaf K content	50	0.943	-0.092	-0.047	0.949
	60	0.971	0.031	0.008	0.924
Leaf Ca content		-0.089	-0.221	-0.968	0.436
		-0.082	-0.366	-0.987	0.483
Pod number per plant		0.925	0.046	0.471	0.648
Seed number per pod		0.715	-0.178	0.583	0.439
1000-seed weight		0.506	-0.234	-0.722	0.890
Seed yield per plant		0.924	0.022	0.454	0.662
Oil content		0.715	0.333	-0.355	0.791
Oil yield per plant		--	0.201	0.232	0.805
Acid value		--	--	0.436	-0.231
Iodine value		--	--	--	-0.359
Saponification value		--	--	--	--

Significant at 5%	r value
	0.950

be explained on the basis of its dependence on the presence of hormones such as GA_3 and/or cytokinin (Roth-Bejerano and Lips, 1970), auxin or its substituents (Ahmad, 1988, 1994; Ahmad and Hayat, 1999). Improvement in chlorophyll content resulting from the application of GA_3 may be related to its roles in various metabolic processes related to chlorophyll synthesis.

The enhancement in the values for net photosynthetic rate, carbonic anhydrase activity and chlorophyll content due to N, P and Ca; for nitrate reductase activity and leaf N content due to N and Ca; for P content due to P and for Ca content due to Ca application in Experiments 3 (Tables 37-38) and Experiment 4 (Tables 50-53) is on expected lines and resembles the findings of Kirkby and Pilbeam (1984), Khan (1996), Mohammad and Khan (1997), Mohammad *et al.* (1997) and Mohammad (2004). This beneficial effect of these nutrient elements may again be ascribed to their roles mentioned earlier (pp. 95, 96) being responsible directly or indirectly for the efficient synthesis of these physiological markers.

It may be added that carbonic anhydrase catalyzes reversible hydration of carbon dioxide and maintains its constant supply to ribulose bisphosphate carboxylase oxygenase in the stroma of the chloroplast. Thus, the enhanced activity of carbonic anhydrase would make considerable quantity of additional carbon dioxide available for the process. Moreover, several compounds involved in photosynthesis, being themselves nitrogenous and phosphatic in nature or becoming active in the presence of Ca, would naturally depend upon these essential nutrient elements for their production or activation (Marschner, 2002). Hence, these factors may be helpful in increasing the net photosynthetic rate of treated plants. Moreover,

elevated nitrate reductase activity may additionally support the photosynthetic efficiency as this enzyme is responsible for the initiation of nitrate metabolism and consequently for protein synthesis which may directly or indirectly be helpful in the process. Also, a substantial increase in chlorophyll content should have direct impact on net photosynthetic rate. A contribution of carbonic anhydrase and nitrate reductase activities and of chlorophyll content to net photosynthetic rate is also borne out from the correlation studies in which these parameters have been noted to be strongly and positively correlated with net photosynthetic rate (Tables 57-59).

The improvement in the leaf N, P and Ca content resulting from the application of N, P and Ca respectively may be ascribed to their ready availability in the soil or foliage. As mentioned earlier, these nutrients play important roles in plants (pp. 95, 96) and thus their enhanced content in plants may directly or indirectly help in the production of dry matter of treated plants. The correlation studies also reveal this proposition as there is a positive and significant correlation between these nutrients and dry matter of plants (Tables 57-59).

5.3 Yield parameters

The highest value for pods and seed yield per plant of Pusa Bold, Pusa Jaikisan, Rohini and Varuna; seeds per pod of Pusa Jaikisan and Rohini; 1000-seed weight of Pusa Jaikisan, Rohini and Varuna; and oil content of Pusa Jaikisan and Varuna and the lowest value for these parameters (except seeds per pod) of Suraj in Experiment 1 (Tables 15-16) could be ascribed to the variations in their genetic make-up. Similar genotype variations in yield parameters have also been reported by

Mohammad *et al.* (1984), Vasi *et al.* (1986), Chaturvedi *et al.* (1988), Sharma (1993), Shukla and Kumar (1994), Mohammad and Khan (1997), Gurjar and Chauhan (1997), Patidar *et al.* (2000), Singh *et al.* (2002), and Siddiqui and Mohammad (2004).

The observed increase in pod number per plant over the water-treated control resulting from the application of GA_3 in Experiment 2 (Table 29) is noteworthy as far as yield characteristics are concerned. An improvement in pod number due to GA_3 treatment has also been reported by Singh and Kumar (1991), Khan (1996), Khan *et al.* (1996, 2002) and Khan and Samiullah (2003). It has been shown that exogenous application of GA_3 promotes differentiation leading to enhanced number of flowers which develop into pods (Huttly and Phillips, 1995; Mobin, 1999; Buchanan *et al.* 2000; Marschner, 2002). Moreover, GA_3 treatment may be helpful in the desirable development of under-developed pods particularly at the terminal end of branches as GA_3 causes cell division and cell enlargement (Liu and Loy, 1976; Moore, 1989; Huttly and Phillips, 1995; Arteca, 1996; Marschner, 2002). Its promoting effect on net photosynthetic rate (Afroz *et al.*, 2005), membrane permeability (Wood and Paleg, 1972, 1974; Crozier and Turnbull, 1984) and transport of photosynthates (Mulligan and Patrick, 1979, Aloni *et al.*, 1986, Dae *et al.*, 1986; Estruch *et al.*, 1989; Hayat *et al.*, 2001), may be helpful in favouring the partitioning of dry matter towards the developing pods; hence the maximum value for pods per plant in the treated plants (Table 29).

The enhancement in pod number per plant due to N, P and Ca application; seed number per pod due to N and 1000-seed weight and oil

content due to P application over the no-nutrient control in Experiment 3 (Tables 44, 45) and Experiment 4 (Table 54) is not unexpected. These results resemble those of other workers, including Rathore and Manohar (1990), Saran and Giri (1990), Agarwal and Gupta (1991), Joshi *et al.* (1991), Rana *et al.* (1991), Singh *et al.* (1991),Prasad and Shukla (1992), Tomer *et al.* (1992a, b), Arthamwar (1996), Patil *et al.* (1996), Khafi *et al.* (1997),Puri *et al.* (1999), Bhari *et al.* (2000),Khan *et al.* (2001), Kumar *et al.* (2001), Shanker *et al.* (2001, Mohammad (2004) and Pandey and Bharti (2005).

As mentioned earlier (pp. 95, 96), the observed improvement in the yield characteristics of treated plants may be ascribed to the roles of the nutrient elements tested, as these are known to be directly or indirectly responsible for growth and development of plants (Marschner, 2002). Moreover, N and P also play an important role in root development and early establishment of plants leading to better absorption of nutrients and water from soils leading increased assimilation as also translocation of photosynthates and this would naturally be manifested in overall improvement in growth and yield characteristics (Patidar *et al.*, 2000). The ameliorative effect of P on 1000-seed weight and oil content may be explained on the basis of its important role in the anabolism of various macromolecules in seed cells, including proteins, phospholipids and triglycerides (Stryer, 1999). The increment in pod number per plant and seeds per pod due to the application of Ca also seems logical as it plays a significant role in differentiation (Hewitt, 1963; Marschner, 2002).

The improved yield attributing parameters of treated plants, particularly pod number per plant, seem to contribute to increased seed yield. This assumption is confirmed by the correlation studies wherein various yield parameters were found to be positively correlated with seed yield (Tables 57-59). Lastly, the reason for the higher value for oil yield per plant in Experiments 2-4 is not far to seek. The enhancement in seed yield, coupled with higher oil content, is likely to be responsible for the observed high oil yield (Tables 31, 46, 55).

5.4 Quality parameters

As noted earlier (pp. 59, 60), the oil was analyzed for three quality characteristics, namely acid, iodine and saponification value. It is worth mentioning that acid value denotes the keeping quality of oil, the lower value indicating improved shelf life of the oil. Iodine value shows the presence of double bonds in the oil the lower value of which is supposed to be good for hydrogenation. Saponification value indicates digestibility of oil. High value means better digestibility.

With reference to the significance of the quality parameters of oil, variations in iodine value (lowest in Kesri-100, Rohini and Varuna and highest in Pusa Bold, Pusa Jaikisan, Suraj and T-4001 and of saponification value (maximum in Pusa bold, Pusa Jaikisan, Rohini and Varuna and minimum in Dhanya Laha, Nath Sona-212, Pusa Agrani and T-4001 in Experiment 1 (Table 17) could be expected on genetic consideration and corroborate similar variations noted by Mohammad *et al.* (1984), Khan *et al.* (1990), Mohammad 1992 and Sharma *et al.* (1997) in the case of other varieties of mustard.

On the other hand, the non-significant effect of the tested range of soaking and spray treatment of GA_3 alone on the three quality parameters in Experiment 2 (Table 32) suggests that exogenous application of GA_3 does not play any significant role in affecting the quality of oil.

The observed decrease in iodine value due to increasing levels of N up to N_{90} and the increase in saponification value resulting from the application of graded levels of P up to P_{30} and of Ca up to Ca_1 is welcome as such a trend is good as far as the quality of oil is concerned. These results broadly corroborate the findings of Mohammad *et al.* (1985) and Khan *et al.* (1990).

The efficacy of leaf-applied GA_3 over pre-sowing seed treatment with it in the case of most parameters studied (Tables 18-32) may be attributed not only to its ready availability at the site of active metabolism (leaves) but also to increased demand at the most crucial stage of crop growth (40 DAS). A similar superiority of foliar application of GA_3 over pre-sowing seed treatment has also been reported by Khan and Samiullah (2003).

Lastly, treatment 10^{-6}M GA_3 applied to seeds before sowing and to foliage in Experiment 2, the nutrient combination $N_{90}P_{30}K_{30}$ applied to GA_3 treated plants in Experiment 3 and application of leaf-applied Ca at the rate of 1 kg/ha in Experiment 4 seem to be optimum on the basis of their effect on the parameters studied (Tables 18-32, 33-47, 48-56).

From the foregoing discussion, the following points emerge and these may be claimed as first report in the literature:

(1) The comparative performance of eighteen newly evolved high yielding varieties of mustard, namely Alankar, Amar, Basanti, Black Diamand-21, BS-2 Chapka, Dhanya Laha, Kala Moti, Kesri – 100, Krishna-1034, Mahyco Bold, Nath Sona – 212, Pusa Agrani, Pusa Bold, Pusa Jaikisan, Rohini, Suraj, T-4001 and Varuna grown with a uniform basal dose of N,P and K, was studied under the agro-climatic conditions of western Uttar Pradesh. The data revealed that varieties Rohini, Pusa Jaikisan, Varuna and often Pusa Bold proved superior to others in respect of most parameters studied, including seed and oil yield.

Varieties Rohini, Varuna and Kesri-100 exhibited lowest iodine value (suitable for hydrogenation) and Rohini, Varuna, Pusa Jaikisan and Pusa Bold showed highest saponification value (better digestibility).

(2) The performance of variety Rohini (selected on the basis of the data of Experiment 1) was studied in detail in relation to pre-sowing seed treatment and foliar application of GA_3 in the presence of a uniform basal dose of N, P and K. Pre-sowing seed treatment of Rohini ($S10^{-6}M$ GA_3) and foliar treatment ($F10^{-6}$ M GA_3), alone or in combination proved best for most parameters, including seed and oil yield.

Inspite of a non-significant effect on leaf N, P and K content, the spectacular increase in dry matter production by GA_3 application results in enhanced accumulation of these nutrients.

(3) The optimum requirement for basal N and P (with uniform dose of K) was determined for Rohini grown with best combination of soaking

and spray of GA_3 ($S10^{-6}M$ + $F10^{-6}M$) obtained from the data of Experiment 2. Application of 90 kg N/ha and 30 kg P/ha, alone as well as in combination, proved best for most parameters, including seed and oil yield.

Improvement in the dry matter production of Rohini with increased leaf N and P content resulting from the application of these nutrients also suggests that they help in enhanced absorption of these nutrients probably due to their ready availability.

(4) The effect of foliar application of Ca was studied together with the best combination of soaking plus spray of GA_3 ($S10^{-6}M$ + $F10^{-6}M$ based on the data of Experiment 2) on plants receiving the best dose of basal N and P, with uniform K, ($N_{90}P_{30}K_{30}$ determined in Experiment 3). Foliar application of 1 kg Ca/ha proved best for most parameters, including seed and oil yield.

Enhanced production of dry matter with increased leaf N and Ca content (inspite of non-significant P and K content) resulting from Ca spray suggests that it facilitates absorption of these nutrients.

Increase in Ca content of plants due to spray of Ca seems to be helpful in providing mechanical strength to the plants which would be expected to help in preventing lodging.

(5) Lastly, the factors that contributed towards maximization of seed yield were the increase in (i) shoot length per plant (ii) leaf area per plant (iii) fresh weight per plant (iv) dry weight per plant (v) net photosynthetic rate (vi) carbonic anhydrase activity (vii) nitrate reductase activity (viii) leaf chlorophyll content (ix) leaf N, P, K and

Ca content (x) pod number per plant, (xi) seed number per pod and (xii) 1000-seed weight. This conclusion is not only based on the data but also on computation of coefficients of correlation.

It may be concluded that varieties Pusa Bold, Pusa Jaikisan, Varuna and particularly Rohini are equally adapted to the agroclimatic conditions of western Uttar Pradesh and the genetic potential of Rohini could be fully realized economically if it is grown in the soil receiving a uniform basal dose of 90 kg N + 30 kg P + 30 kg K/ha, with seeds soaked in 10^{-6} M GA_3 and the subsequently produced plants sprayed with 10^{-6}M GA_3 plus 1 kg Ca/ha at 40 DAS.

Summary

SUMMARY

The present thesis comprises six chapters. In chapter 1 (Introduction), the importance of the problem "Study of the effect of GA_3, N, P, K and Ca application on the performance of mustard" has been discussed briefly. In view of the lacunae in the understanding of the problem, justifications have been put forward for undertaking the present work. Moreover, the logical basis of each of the four experiments undertaken has been mentioned briefly.

In Chapter 2 (Review of Literature), general aspects of rapeseed-mustard, phytohormones and inorganic nutrition, physiological roles of GA_3, N, P, K and Ca and effect of their application on performance of mustard have been reviewed with special reference to the work done in India during the last two decades.

Chapter 3 (Materials and Methods) deals with the details of materials and methods employed for the four pot experiments conducted and relevant meteorological and edaphic data have been given.

Chapter 4 (Experimental Results) includes the detailed data regarding crop response based on growth, biochemical and physiological, yield and quality parameters. These were mostly found significant on statistical analysis at $p > 0.05$. The important data of the four pot experiments, each conducted in the "rabi" (winter) season, are summarized below.

Experiment 1 was conducted according to a simple randomized design during 2002-2003, to select the most promising variety of mustard (*Brassica juncea* L. Czern. & Coss.) on the basis of a screening test on eighteen newly evolved high yielding varieties, namely Alankar, Amar, Basanti, Black Diamond-21, BS-2 Chapka, Dhanya Laha, Kala Moti, Kesri-100, Krishna 1034, Mahyco Bold, Nath Sona-212, Pusa Agrani, Pusa Bold, Pusa Jaikisan, Rohini, Suraj, T-4001 and Varuna, grown with a uniform basal dose 40 mg N + 14 mg P + 14 mg K/kg soil (90 kg N + 30 kg P + 30 kg K/ha). Growth (shoot length per plant, leaf area per plant, fresh weight per plant and dry weight per plant) and physiological and bio-chemical parameters (net photosynthetic rate, carbonic anhydrase and nitrate reductase activity, leaf chlorophyll content and leaf N, P and K content) were studied at 50 and 60 DAS. Yield parameters (pod number per plant, seed number per pod, 1000-seed weight, seed yield per plant, oil content and oil yield per plant) and quality characteristics (acid, iodine and saponification value) were recorded at harvest. Data revealed that varieties differed critically with regard to parameters studied. Generally speaking, Rohini, Pusa Jaikisan, Varuna and often Pusa Bold gave maximum values. For example, Rohini gave 20.7% more dry matter per plant and 25.9% higher net photosynthetic rate at 60 DAS, 19.5% higher seed yield, 32.0% higher oil yield and 1.6% higher saponification value than Suraj which gave minimum value for most parameters. It is noteworthy that earlier also Rohini proved better in studies at Aligarh.

Experiment 2 was performed according to a factorial randomized design during 2003-2004. The aim of this experiment was to determine the

best concentration of pre-sowing seed treatment and/or foliar application of GA_3 each at 0, 10^{-8}, 10^{-6} and 10^{-4} M GA_3 for Rohini (selected on the basis of the data obtained in Experiment 1). Plants were grown with a uniform basal dose of 90 kg N + 30 kg P + 30 kg K/ha as in Experiment 1. There was a significant effect of pre-sowing seed treatment and foliar application of GA_3, alone as well as in combination, on most parameters studied. The important results are summarized below.

(i) Pre-sowing seed treatment S10^{-6}M GA_3 gave maximum values for most parameters studied. For instance, this treatment increased dry weight by 6.1% and net photosynthetic rate by 8.8% at 60 DAS, seed yield by 7.0% and oil yield by 7.8% over the control.

(ii) Foliar treatment F10^{-6}M GA_3 proved best and produced 7.8% more dry matter and exhibited 13.0% higher net photosynthetic rate at 60 DAS, 9.2% higher seed yield and 6.8% higher oil yield than the control.

(iii) Interaction S10^{-6}M GA_3 x F10^{-6}M GA_3 gave maximum values for most parameters. For example, this treatment increased dry weight by 15.2% and net photosynthetic rate by 24% at 60 DAS, seed yield by 16.5% and oil yield by 13.3% over the control.

(iv) Quality parameters, namely acid, iodine and saponification value of the oil, were not affected by soaking or spray treatments alone or in combination.

Experiment 3, based on a factorial randomized design, was conducted during 2004-2005. The aim of this experiment was to determine the best combination of basal dose of N (0, 30, 60, 90 and 120 kg N/ha) and

P (0, 15, 30 and 45 kg P/ha) in the presence of a uniform dose of 30 kg K/ha. Rohini was grown with the best combination of soaking and spray of GA_3 ($S10^{-6}M + F10^{-6}M$) on the basis of the data of Experiment 2. The effect of N and P as also of their interaction was significant for most parameters studied. The important findings are given below.

(i) Increasing levels of N up to N_{90} increased most parameters. Application of N_{90}, for example, increased dry weight by 9.0% and net photosynthetic rate by 12.8% at 60 DAS, seed yield by 11.7%, oil yield by 8.7% and saponification value by 2.8% over N_0.

(ii) There was an improvement in most parameters with increasing levels of P application, with P_{30} giving maximum value. Application of P_{30} resulted in 5.4% more dry matter and 6.4% higher net photosynthetic rate at 60 DAS, 5.3% higher seed yield, 11.3% higher oil yield and 2.1% higher saponifcation value than P_0.

(iii) Interaction $N_{90}xP_{30}$ proved best for most parameters. This interaction, for example, enhanced dry weight by 15.1% and net photosynthetic rate by 20.6% at 60 DAS, seed yield by 18.0% and oil yield by 20.5% over the no nutrient control (N_0P_0)

Experiment 4 was performed according to a simple randomized design during 2005-2006 to select the best dose of leaf-applied Ca (0, 1, 2 and 3 kg Ca/ha) for mustard variety Rohini grown with the best combination of soaking plus spray of GA_3 ($S10^{-6}M + F10^{-6}M$) selected on the basis of the data of Experiment 2 and of basal N and P determined in Experiment 3. Foliar application of Ca_1 proved best for all parameters. This treatment, for example, increased dry weight by 9.9%, net photosynthetic rate by 13.0%

and leaf Ca content by 14.8% at 60 DAS, seed yield by 11.9%, oil yield by 15.7% and saponification value by 3.2% over the water-sprayed control. Increase in Ca content of the plants due to Ca spray is a welcome observation as it may be helpful in providing mechanical strength to the plants which, of course, may help in prevention of lodging.

In Chapter 5 (Discussion), the main results have been discussed in the light of the findings of earlier researches in our laboratory and elsewhere.

The present chapter (Summary) is a resume of the thesis. It is followed by an up-to-date bibliography of the references cited in the text. An appendix, containing the various formulations employed for chemical analyses, has been appended at the end.

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Appendix

APPENDIX

Sterilization of seeds

10 mg $HgCl_2$ was dissolved in sufficient volume of DDW in 100 ml volumetric flask and the final volume was made using DDW.

GA_3 stock solution (10^{-3}M)

10^{-3}M GA_3 was prepared by dissolving 34.637 g GA_3 in sufficient volume of ethanol in 100 ml volumetric flask. The final volume was made up to the mark using DDW. The required concentrations (10^{-8}, 10^{-6} and 10^{-4}) were prepared by diluting the stock solution using DDW.

Reagents for determination of carbonic anhydrase activity

1 **Bromothymol blue indicator in ethanol (0.002%)**

0.002 g bromothymol blue was dissolved in approximately 100 ml of DDW.

2 **Cystein hydrochloride solution (0.2M)**

48 g cystein hydrochloride was dissolved in sufficient DDW and final volume was made up to 1000 ml using DDW.

3 **Hydrochloric acid (0.05 N)**

4.3 ml pure hydrochloric acid was mixed with 95.7 ml DDW to get 100 ml 0.05 N HCl.

4. **Phosphate buffer (0.2 M) for pH 6.8**

This was prepared by dissolving 27.80 g sodium dihydrogen ortho-phosphate and 53.65 g di-sodium hydrogen ortho-phosphate in sufficient DDW separately and the final volume of each was made up

to 1000 ml using DDW. To get pH 6.8, 5 ml the sodium dihydrogen ortho-phosphate solution was mixed with 49 ml the di-sodium hydrogen ortho-phosphate solution and diluted to 200 ml using DDW.

5. **Sodium bicarbonate solution (0.2 M) in 0.02 M sodium hydroxide solution**

16.8 g sodium bicarbonate was dissolved in 0.02 M sodium hydroxide solution (0.8 g NaOH/l) and final volume was made up to 1000 ml using the sodium hydroxide solution.

Reagents required for the estimation of nitrate reductase activity

1. **Isopropanol solution (5%)**

5 ml isopropanol was mixed with 95 ml DDW.

2. **Naphthylethylenediamine dihydrochloride (NED-HCl) solution (0.02%)**

20 mg naphthylethylenediamine dihydrochloride was dissolved in sufficient DDW and the final volume was made up to 100 ml using DDW.

3. **Phosphate buffer (0.1 M) for pH 7.5**

(a) 13.6 g potassium dihydrogen orthophosphate was dissolved in sufficient DDW and the final volume was made up to 1000 ml using DDW.

(b) 17.42 g dipotassium hydrogen orthophosphate was dissolved in sufficient DDW and final volume was maintained up to 1000 ml using DDW.

160 ml solution (a) was mixed with 840 ml solution (b).

4. **Potassium nitrate solution (0.02 M)**

2.02 g potassium nitrate was dissolved in the sufficient DDW and final volume was maintained up to 1000 ml with DDW.

5. **Sulphanilamide solution (1%)**

1 g sulphanilamide was dissolved in the sufficient volume of 3N hydrochloric acid and the final volume was made up to 100 ml using 3N hydrochloric acid.

80% acetone

80 ml acetone was mixed with 20 ml DDW.

Reagents for the estimation of nitrogen, phosphorus and potassium

1. **Aminonaphthol sulphonic acid**

500 mg 1-amino-2-naphthol-4-sulphonic acid was dissolved in 195 ml 15% sodium bisulphite to which 5 ml 20% sodium sulphite solution was added. The solution was kept in an amber coloured bottle.

2. **Molybdic acid reagent**

6.25 g ammonium molybdate was dissolved in 175 ml 10 N H_2SO_4.

3. **Nessler's reagent**

3.5 g potassium iodide was dissolved in 100 ml DDW to which 4% mercuric chloride was added with stirring until a slide red precipitate remains, then 120 g NaOH was mixed with 250 ml DDW. The mixture was kept in an amber coloured bottle.

4. **Sodium hydroxide solution (2.5 N)**

100 g sodium hydroxide was dissolved in sufficient DDW and the final volume was maintained up to 1000 ml using DDW.

5. **Sodium silicate solution (10%)**

10 g sodium silicate was dissolved in the sufficient DDW and the final volume was made up to 100 ml using DDW.

6. **Sulphuric acid (10N)**

27.2 ml sulphuric acid was mixed with 72.8 ml DDW to get 100 ml 10N H_2SO_4.

Reagents for oil analysis

1. **Hydrochloric acid (0.5 N)**

21.49 ml hydrochloric acid was mixed with 478.51 ml DDW to get 500 ml 0.5N HCl.

2. **Iodine monochloride solution**

13 g iodine was dissolved in a mixture of 300 ml carbon tetrachloride and 700 ml glacial acetic acid and the resulting solution was divided into solution A and B. To 20 ml of solution A, 15 ml of the potassium iodide solution and 100 ml DDW were added and titrated against 0.1 N sodium thiosulphate solution, using starch solution as an indicator. Chlorine gas was passed through solution B until the amount of the sodium thiosulphate solution required for the titration was not more than double of that needed in solution A.

3. **Phenolphthalein solution**

1 g phenolphthalein was dissolved in the sufficient volume of 95% ethanol and the volume was made up to 100 ml using the etanol.

4. **Potassium hydroxide solution (0.1 N KOH)**

5.6 g potassium hydroxide was dissolved in the sufficient volume of 95% ethanol and the final volume was made up to 1 litre using the ethanol.

5. **Potassium hydroxide solution (0.5 N KOH)**

28 g potassium hydroxide was dissolved in the sufficient volume of 95% ethanol and the final volume was made up to 1 litre using the ethanol.

6. **Potassium iodide solution**

150 g potassium iodide was dissolved in the sufficient volume of DDW and the final volume was made up to 1 litre using DDW.

7. **Sodium thiosulphate solution (0.1 N)**

24.8 g sodium thiosulphate was dissolved in the sufficient volume of DDW and the final volume was made up to 1 litre using DDW.

8. **Solvent mixture**

Ethanol (95%) was mixed with diethyl ether in 1:1 ratio. This mixture of solvents was neutralized just before use by means of 0.1 N potassium hydroxide solution in the presence of phenolphthalein solution as an indicator.

9. **Starch solution (1%)**

1 g soluble starch was dissolved in the sufficient volume of DDW and the final volume was made up to 100 ml using DDW.